

**Single leg hopping in children with and without  
Fetal Alcohol Spectrum Disorder:  
A descriptive study of dynamic postural stability and kinematics**

by  
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## **Declaration**

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## **Abstract**

### **Introduction**

Fetal Alcohol Spectrum Disorder (FASD) is a leading preventable cause of acquired developmental disabilities. Impairments of motor function and dynamic postural stability (DPS) are found in children with FASD. These impairments may negatively impact on these children's ability to perform their required activities of daily living and engage with their peers in play and sporting activities. To date no research has been conducted on DPS in children with FASD in South Africa.

### **Aim**

DPS and kinematics during single leg hopping were described in two groups of typically developed nine-year-old children from an urban and rural setting (controls) and a group of nine-year-old children with FASD from a rural setting (cases). Any differences in DPS and kinematics between the three groups were also determined.

### **Purpose of the study**

Identifying and describing potential motor and DPS impairments in South African children with FASD will add to the body of available research and could provide the basis for the development of interventions aimed at improving overall motor function of these children, and therefore their ability to participate better in their activities of daily living.

### **Methodology**

Participants performed a consecutive single leg hopping task and landed on a pressure mat to stabilise on one leg. Motion analysis systems and a pressure mat were used to describe 1) spatiotemporal and centre of pressure (COP) parameters and 2) joint kinematics i.e. hip, knee and ankle angles in the sagittal plane. Spatiotemporal parameters included stance and swing times and speed. COP parameters included anteroposterior

(AP) and mediolateral (ML) velocity and range of motion (ROM). Descriptive results are presented in median and ranges and differences between groups were determined by Kruskal-Wallis and Mann-Whitney U statistical tests. The level of significance was set at  $p < 0.05$ .

## Results

Fifty-six children participated; 14 children with FASD (cases), 14 rural controls and 28 urban controls. The urban controls had statistically significant longer stance and swing times ( $p < 0.001$ ) than the case and rural control groups. COP parameters were not statistically significantly different; however the case group displayed greater AP velocity and AP ROM values compared to both control groups ( $AP_{vel}$ :  $p = 0.78$ ;  $AP_{ROM}$ :  $p = 0.66$ ). In terms of kinematics, the urban controls hopped with statistically significant greater hip flexion compared to the case group ( $p = 0.017$ ). Rural and urban controls hopped with more knee flexion compared to the case group, although this was not significant ( $p = 0.16$ ). The cases and rural controls showed statistically significant greater knee flexion at initial foot contact (IFC) onto the pressure mat than the urban controls (cases and urban controls:  $p = 0.04$ ; rural and urban controls:  $p < 0.001$ ). The urban control group landed in statistically significant more plantarflexion at IFC onto the mat than the case group ( $p < 0.001$ ) and the rural control group ( $p = 0.03$ ) and during landing, the urban control group moved into statistically significant more hip flexion compared to the case group ( $p = 0.015$ ) and the rural control group ( $p = 0.026$ ).

## Conclusion

The differences in spatiotemporal, COP and kinematic parameters highlight different movement strategies and DPS capabilities between the groups. The case group hopped in a more extended position of the lower limbs and displayed increased COP AP velocity and ROM compared to the control groups, which may be an indication of impaired DPS.

Identifying and exploring the aspects that underlie these impairments through objective measurement methods may assist in the development of evidence-based physiotherapy treatments for these children. This is the first study of its kind in South Africa and further research is warranted.

**Keywords:** *Fetal Alcohol Spectrum Disorder, postural stability, descriptive study*

## **Opsomming**

### **Inleiding**

Fetale Alkohol Spektrum Afwykings (FASA) is 'n voorste voorkombare oorsaak van ontwikkelingsgestremdhede. Gebreke in motoriese funksie en dinamiese posturale stabiliteit (DPS) word in kinders met FASA gevind. Hierdie gebreke mag 'n negatiewe invloed hê op hierdie kinders se vermoë om hul vereiste daaglikse aktiwiteite uit te voer en om saam met hul portuurgroep deel te neem aan speel- en sportaktiwiteite. Tot op hede is nog geen navorsing oor DPS in kinders met FASA in Suid-Afrika gedoen nie.

### **Doelwit**

DPS en kinematika gedurende een-been hop is in twee groepe van tipies ontwikkelde negejarige kinders van 'n stedelike en landelike omgewing (kontroles) en 'n groep negejarige kinders met FASA van 'n landelike omgewing (gevalle) beskryf. Enige verskille in DPS en kinematika tussen die drie groepe is ook bepaal.

### **Doel van die studie**

Identifisering en beskrywing van potensiële motoriese en DPS gebreke in Suid-Afrikaanse kinders met FASA sal 'n bydra maak tot die liggaam van beskikbare navorsing en kan die basis wees vir die ontwikkeling van intervensies met die doel om algehele motorise funksie van hierdie kinders te verbeter, en daarom hul vermoë om deel te neem aan hul daaglikse aktiwiteite te verbeter.

### **Metodologie**

Deelnemers het 'n agtereenvolgende een-been hop taak uitgevoer en geland op 'n drukmat om te stabiliseer op een been. Bewegingsanaliserende sisteme en 'n drukmat is gebruik om 1) tydruimtelike en middelpuntdruk (MPD) veranderlikes en 2) gewrigskinematika, maw. hoeke van die heup-, knie- en enkel in die sagittale vlak te

beskryf. Tydruimtelike veranderlikes het staan- en swaaitye en spoed ingesluit. MPD veranderlikes het anteroposterior (AP) en mediolaterale (ML) snelheid en omvang van beweging (OVB) ingesluit. Beskrywende resultate word in mediaan en omvange voorgestel en verskille tussen die groepe is met Kruskal-Wallis en Mann-Whitney U toetse bepaal. Die vlak van beduidendheid was by  $p < 0.05$  vasgestel.

## Resultate

Ses-en-vyftig kinders het deelgeneem; 14 kinders met FASA (gevalle), 14 landelike kontroles en 28 stedelike kontroles. Die stedelike kontrole groep het statisties beduidend langer staan- en swaaitye ( $p < 0.001$ ) gehad teenoor die gevalle en landelike kontrole groepe. MPD-veranderlikes was nie statisties beduidend verskillend nie; alhoewel die gevalle-groep groter AP snelhede en AP OVB waardes in vergelyking met albei die kontrolegroepe getoon het (AP snelhede:  $p = 0.78$ ; AP OVB:  $p = 0.66$ ). In terme van kinematika het die stedelike kontrole groep met statisties beduidend meer heupfleksie gehop in vergelyking met die gevalle-groep ( $p = 0.017$ ). Landelike en stedelike kontrole groepe het met meer kniefleksie gehop in vergelyking met die gevalle-groep, alhoewel dit nie beduidend was nie ( $p = 0.16$ ).

Die gevalle-groep en die landelike kontrole groep het statisties beduidend meer kniefleksie by inisiële voetkontak (IVK) op die drukmat getoon as die stedelike kontrole groep. (gevalle- en stedelike kontrole groep:  $p = 0.04$ ; landelike en stedelike kontrole groepe:  $p < 0.001$ ). Die stedelike kontrole groep het met statisties beduidend meer plantaarfleksie by IVK op die mat geland as die gevalle-groep ( $p < 0.001$ ) en die landelike kontrole groep ( $p = 0.03$ ). Gedurende die landing het die stedelike kontrole groep in statisties beduidend meer heupfleksie inbeweeg in vergelyking met die gevalle-groep ( $p = 0.015$ ) en die landelike kontrole groep ( $p = 0.026$ ).

## **Gevolgtrekking**

Die verskille in tydruimtelike, MPD en kinematiese veranderlikes beklemtoon verskillende bewegingstrategieë en DPS vermoëns tussen die groepe. Die gevalle-groep het in 'n meer geëkstendeerde posisie van die onderste ledemaat gehop en het verhoogde MPD AP snelhede en OVB getoon teenoor die kontrole groepe wat moontlik 'n aanduiding kan wees van gebrekkige DPS. Identifisering van en ondersoek instel na die onderliggende aspekte van hierdie gestremdhede, deur gebruik te maak van objektiewe metodes van meting, mag bydrae tot die ontwikkeling van bewys-gebaseerde fisioterapeutiese behandeling vir hierdie kinders. Hierdie is die eerste studie van sy soort in Suid-Afrika en verdere navorsing is geregverdig.

**Sleutelwoorde:** *Fetale Alkohol Spektrum Afwyking, dinamiese posturale stabiliteit, beskrywende studie.*



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## List of abbreviations

<b>ADHD</b>	Attention Deficit Hyperactivity Disorder
<b>AP</b>	Anteroposterior
<b>ARBD</b>	Alcohol-related birth defects
<b>ARND</b>	Alcohol-related neurodevelopmental disorder
<b>BMI</b>	Body mass index
<b>BOTMP</b>	Bruininks-Oseretsky Test of Motor Proficiency
<b>CNS</b>	Central nervous system
<b>COM</b>	Centre of Mass
<b>COMPS</b>	Clinical Observations of Motor and Postural Skills
<b>COP</b>	Centre of Pressure
<b>DGI</b>	Dynamic Gait Index
<b>DPSI</b>	Dynamic postural stability index
<b>EMG</b>	Electromyography
<b>FAS</b>	Fetal Alcohol Syndrome
<b>FASD</b>	Fetal Alcohol Spectrum Disorder
<b>GMDS</b>	Griffiths Mental Development Scale
<b>GRF</b>	Ground reaction force
<b>IFC</b>	Initial foot contact
<b>MABC</b>	Movement Assessment Battery for Children
<b>ML</b>	Mediolateral
<b>MuMBER</b>	Multi-modal Balance Entrainment System
<b>NEPSY</b>	Developmental Neuropsychological Examination
<b>OFC</b>	Occipital frontal circumference
<b>PAE</b>	Prenatal alcohol exposure
<b>P-CTSIB-2</b>	Paediatric Clinical Test of Sensory Interaction for Balance-2
<b>PFAS</b>	Partial Fetal Alcohol Syndrome
<b>PI</b>	Principal investigator
<b>ROM</b>	Range of motion
<b>SES</b>	Socio-economic status



## **List of abbreviations (continued)**

<b>SLH</b>	Single leg hop/hopping
<b>TTS</b>	Time to stability
<b>USA</b>	United States of America
<b>V</b>	Vertical
<b>WC</b>	Western Cape
<b>WCED</b>	Western Cape Education Department
<b>WHO</b>	World Health Organisation

## Glossary of Terms

**Centre of mass:** The centre point of the total body mass in 3D orientation and is the weighted average of the centre point of each body segment (Winter, 1995).

**Centre of pressure:** The centre point of all external ground reaction forces acting on the plantar surface of the foot (Lugade & Kaufman, 2014). It is independent of the centre of mass (Winter, 1995).

**Dynamic postural stability:** The ability to maintain equilibrium of the body while moving from a dynamic to a static state (Wikstrom et al, 2005b).

**Kinematics:** The study of the motion of the body without considering its mass or the forces acting on it (The American Heritage® Stedman's Medical Dictionary, 2002)

**Spatiotemporal parameters:** Quantitative descriptions of the main events of gait, ie. weight-acceptance, single-limb support and swing limb movement (Bugane et al, 2012).

# Chapter 1

## INTRODUCTION

Fetal Alcohol Spectrum Disorder (FASD) is an umbrella term for a complex group of impairments caused by prenatal alcohol exposure (PAE) (WHO, 2014). Within this disorder, four diagnoses fall on a continuum of severity: Fetal Alcohol Syndrome (FAS), the most severe form, partial FAS (PFAS), alcohol-related birth defects (ARBD), and alcohol-related neurodevelopmental disorder (ARND), the least severe form (Riley et al, 2011; Senturias et al, 2014). This disorder has become widely recognised as the leading preventable cause of acquired developmental disabilities in children (Memo et al, 2013; Hebebrand & Verhulst, 2014; Fitzpatrick et al, 2015; Hoyme et al, 2016) and is the most common birth defect in South Africa, affecting more than one million South Africans (Bulletin of the World Health Organization 2011).

FASD can manifest as a number of health problems including growth retardation, birth defects, cognitive delay, speech and language deficits, and motor function impairments and therefore people with this disorder may require life-long assistance to meet their needs (Popova et al, 2011; Mattson & Riley, 1998; Mattson et al, 2011). FASD is an extensive burden to society with regards to the cost of associated health and other care required for those affected (Popova et al, 2012). In the Western Cape (WC) of South Africa, it is estimated that of the total WC health budget for 2010/2011, 5% was used for the management of children with FASD (Crede et al, 2011). Considering that FASD is a preventable disorder, it is alarming that such a significant portion of the budget is required for these children (Crede et al, 2011), and this highlights the need for efficient management strategies to improve their overall health profiles.

A recent systematic review examining worldwide prevalence rates of FASD revealed that South Africa is estimated to have the highest rates worldwide of FAS (55.42 per 1000); ARND (20.25 per 1000) and FASD (113.22 per 1000) (Roozen et al, 2016). May et al (2016) performed the most recent prevalence study in South Africa in four small towns and their surrounding rural areas in the WC (May et al, 2016). The prevalence rates found were considerably higher than previously recorded, with FASD rates estimated at 182.7-258.9 per 1000 and FAS at 93-128 per 1000 (May et al, 2016). This far exceeds prevalence rates found or reported on in any other country in the world (May et al, 2016). The most recent prevalence studies conducted in the United States of America (USA) and Australia found FASD prevalence rates of 33.5 per 1000 and 1.06 per 1000 respectively (Roozen et al, 2016).

FASD prevalence studies in low- and low-middle-income countries (other than South Africa) are limited. One recent study conducted in Brazil, investigating the prevalence of FASD in a population of children living in orphanages, found a FASD prevalence rate of 180.85 per 1000 (Strömberg et al, 2014). Another study conducted in a rural province of Croatia found a combined FAS and PFAS prevalence rate of 66.7 per 1000 (Petković & Barišić, 2013). The prevalence rates of FASD in South Africa found by May et al (2016) exceed the rates found in both of these prevalence studies conducted in low-income countries, but with limited prevalence research in lower income countries it is difficult to make direct and conclusive comparisons with the FASD rates found in South Africa.

Prevalence rates of FASD are found to be higher in rural compared to urban areas in the WC (May et al, 2016), as well as in isolated towns or villages, such as De Aar in the Northern Cape (Urban et al, 2008) and Aurora in the WC (Olivier et al, 2013). Factors associated with poverty, such as rural-living and lower socio-economic status (SES) have

been linked to a higher risk of FASD (Abel & Hannigan, 1995; May et al, 2005; 2008; May & Gossage, 2011). In South Africa, rural and farming areas are unique in terms of their history and drinking culture since, historically, wine and alcohol were given to rural workers and families on agriculture farms as a form of payment (May et al, 2007). Despite this practice being outlawed approximately 40 years ago, it has shaped the societal pattern of drinking in these communities (May et al, 2000; Viljoen et al, 2002, May et al, 2007) and may explain the high prevalence rates.

In diagnosing FASD in children, four diagnostic checklists are commonly used and all checklists include three key features: growth deficiency; characteristic facial features and central nervous system (CNS) anomalies or dysfunctions (O'Leary, 2004). The CNS criteria are classified as structural, functional and neurological abnormalities (Roszel, 2015). The multitude of CNS abnormalities found in children with FASD indicates that the brain is the most severely affected structure by PAE (Caputo et al, 2016). Along with deficits of learning, memory, attention and speech; motor impairments including poor coordination, impaired motor sequencing and control and poor balance and postural stability have been reported in children with FASD (Simmons et al, 2010; Barr et al, 1990; Roebuck et al, 1998a; 1998b; Kalberg et al, 2006; Kooistra et al, 2009; Jirikowic et al, 2013; Williams et al, 2014).

Postural stability and balance control are essential requirements for motor development in children (De Kegel et al, 2011). Poor postural stability can impede children's participation in play, engagement in sports and other activities of daily living and may impact negatively on their ability to perform simple tasks such as sitting still at a desk to learn, maintaining attention and performing more complex movements required when playing on the playground and engaging in sporting activities (Jirikowic et al, 2013). Clinically, postural

stability is evaluated through functional tasks with balance elements and these tasks often form part of standardised motor assessment batteries used in children, such as the Movement Assessment Battery for Children (MABC) (Kooistra et al, 2009; Bay et al, 2012; Jirikowic et al, 2013; Kesmodel et al, 2013) and the Bruininks-Oseretsky Test of Motor Proficiency (BOTMP) (Chandler et al, 1996; Jirikowic et al, 2008; Lucas et al, 2013). The MABC and BOTMP are comprised of several motor function tests including the functional task of single leg hopping (SLH); either consecutive hopping in consecutive squares (MABC) or stationary hopping (BOTMP). SLH is a fundamental task and milestone for children as the developing body learns to compensate for changes in perceived gravity effects and inertial changes, as well as weight adaptations onto one leg for control in asymmetrical tasks (Parker et al, 1993). The motor control system is therefore challenged by SLH and this in turn allows for the development of new patterns of coordinated movement (Parker et al, 1993). Therefore, children should develop hopping skills to improve muscular strength, dynamic balance and controlled, rhythmic and asymmetrical movement (Holm et al, 2009) in order to become proficient movers and be able to incorporate these motor abilities in other activities such as play, sport and dancing (Haywood & Getchell, 2005).

Considering that poor balance and postural stability are found in children with FASD, evaluating complex motor tasks such as SLH may provide insight into the fundamental neuro-motor mechanisms that underpin this disorder (Kooistra et al, 2009; Chandler et al, 1996). Objective measurement methods, such as specialised human motion analysis, can play an important role in the assessment of dynamic tasks and overall motor function in children with FASD (Domellöf et al, 2011). Therefore, combining the consecutive SLH task (as tested in the MABC) with objective, specialised measurement methods, could provide further insight into the impairments found in children with FASD. Findings from this type of

motor function assessment could assist in planning evidence-based treatment regimes aimed at improving the overall neurobehavioural development and health profiles of these children (Kalberg et al, 2006). To date no local or international research has used motion analysis techniques to examine a complex functional motor task such as SLH performed by children with FASD.

In 2014, a South African study examined postural stability and joint kinematics during consecutive SLH in a group of nine-year-old children living in a rural town in the WC, diagnosed with FASD (cases), and a group of children from the same town, similar in age and gender without FASD (controls) (Ethics reference no. N13/10/140; see Addendum A). The aim of this study was to describe and analyse dynamic postural stability and joint kinematics during a consecutive SLH task in typically developed children from an urban setting (captured in 2016) and to compare the data to the historical rural dataset (captured in 2014) of children with and without FASD. There is very little research on consecutive SLH in children available, and therefore it was considered necessary to include an urban control group so as to accumulate more normative data for this dynamic motor function task for comparison purposes. The urban control group included in the 2016 study was geographically closer to the research institution and therefore provided easier access to gain this normative data for comparison to the 2014 dataset.

## **Chapter 2**

### **SCOPING REVIEW**

#### **Gross motor deficits in children with FASD and the use of single leg hop testing**

##### **2.1 Introduction**

FASD is a developmental disorder associated with a wide range of neurological and behavioural impairments including problems with learning and memory, speech, attention, visual-spatial function, executive cognitive functioning and fine and gross motor skills (Mattson & Riley, 1998; Mattson et al, 2011). Neuroimaging research in people with FASD commonly demonstrates a reduction of white and grey brain matter volume, malformations of certain areas of the brain and poorly developed and disorganised brain vasculature, highlighting the global effect of PAE on structures of the developing brain (Caputo et al, 2016; Donald et al, 2015; Chen et al, 2012).

Areas of the brain that are most vulnerable to PAE include the corpus callosum (Dodge et al, 2009; Chen et al, 2012; Sowell et al, 2001), the cerebellum (Archibald et al, 2001; O'Hare et al, 2005; Donald et al, 2015) and the basal ganglia (Archibald et al, 2001; Rousotte et al, 2012; Lebel et al, 2008). The cerebellum and the basal ganglia are associated with sensory-motor functions including coordination, motor control and sequencing, balance and postural stability (Domellöf et al, 2011; Westcott McCoy et al, 2015). Thus, deficits associated with gross motor performance are commonly found in children with FASD and impairments are evident mainly in the areas of balance, coordination, postural stability and ball skills (Kalberg et al, 2006; Bay & Kesmodel, 2011; Lucas et al, 2014). These are fundamental motor skills used on a daily basis by children,



for example during running and playing with peers in the school ground, balancing to dress, and sitting quietly and maintaining attention at school (Lucas et al, 2014).

Although impaired motor development is not considered to be a primary diagnostic criteria for FASD (Kalberg et al, 2006), gross and fine motor function assessment of children prenatally exposed to alcohol is recommended (Lucas et al, 2014). Researchers are thus showing growing interest and awareness of the importance of motor function in children with FASD in terms of overall neurobehavioural development and abilities, as well as for treatment of the motor impairments found in these children (Kalberg et al, 2006). Standardised assessment tools, such as the MABC and the BOTMP, are commonly used to evaluate gross motor function in children with FASD. In these assessments, examiners rate the child's performance on different motor tasks and composite scores of overall motor function are provided. However, the construct validity of these tests is questioned as there is little evidence that the performance tasks of these assessments actually test the motor skills they claim to, and ceiling effects are reported due to the tasks being too simple for the children being tested (Brown et al, 2009; Lucas et al, 2013).

These tests provide little insight into how a child is performing a task in terms of specific motor abilities, such as movement timing and control, coordination and dynamic postural control. Research using objective measurement methods, such as human motion analysis, to describe specific motor abilities in children with FASD may provide a better understanding of the underlying neuro-motor mechanisms of motor deficits commonly found in these children (Kooistra et al, 2009; Domellöf et al, 2011).

Research evaluating motor skills and dynamic postural stability (DPS) in both healthy populations and populations with knee or ankle injury/surgery commonly includes single

leg hop/land tests. This dynamic task sufficiently challenges the postural control system and reflects global neuromuscular control and everyday functional movement more accurately than static tasks (Fransz et al, 2016; Fransz et al, 2013; Ross & Guskiewicz, 2004; Reid et al, 2007). Through the use of objective measurement instruments such as human motion analysis systems and force plates, postural stability parameters and kinematics can be objectively measured during single leg hop/land tests so as to examine overall neuromuscular control and stability during a functional task (Fransz et al, 2016; Nyland et al, 2011; Oberlander et al, 2012).

To date no research has been conducted using motion analysis systems to investigate DPS and kinematics through the use of a SLH task in children with FASD. However, the variance of SLH tests used across literature, as well as the different outcome parameters used to describe and quantify postural stability, poses a challenge when planning and designing research protocols examining this task (Fransz et al, 2013).

The aim of the scoping review was to firstly describe motor impairments in children with FASD and the tests used to measure these impairments, and secondly to describe SLH test protocols used to assess DPS and the main outcome parameters thereof. The findings of the review will inform how SLH can be used to evaluate motor functioning in children with FASD.

## **2.2 Methods**

### **2.2.1 Search strategies**

Computerised databases including PubMed, Science Direct, Scopus, Academic Search Premier, CINAHL, MEDLINE, Health Source: Nursing Edition and Health Source: Consumer Edition were searched from March 2015 to April 2016. To identify studies

relevant to the purpose of the scoping review, broad searches were conducted firstly on FAS/FASD, the motor and dynamic stability deficits found in this population and the functional motor tests used in this population. Secondly, broad searches were conducted on SLH tests, the use of these tests to examine DPS and the outcome parameters thereof.

Search strategy A concerned FASD and motor function and included all relevant keyword combinations of Fetal Alcohol Syndrome/Spectrum Disorder and motor function; motor control; postural control/stability; balance; measurement tools/tests. Search strategy B concerned SLH and its outcome parameters and included all relevant keyword combinations such as single leg hop/jump/land and dynamic stability; biomechanics; postural control; motion analysis and centre of pressure. The search strategies and keyword combinations can be seen in Table 2.1. Limits on all searches were English and human, with additional limits applied to each database. Addendum B contains the detailed search strategy and number of hits identified per database. To identify other potentially relevant articles, the reference lists of all included articles as well as any relevant systematic reviews, were examined.

**Table 2.1 Database search strategies**

<b>Search Strategy A</b>	<b>Search Strategy B</b>
<b>Keyword combinations</b>	<b>Keyword combinations</b>
1. Fetal alcohol s*	1. Single leg hop*
2. #1 & motor function	2. Single leg jump*
3. #1 & motor control	3. Single leg land*
4. #1 & postural control	4. #1 - #3 & dynamic stability
5. #1 & postural stability	5. #1 - #3 & biomechanics
6. #1 & balance	6. #1 - #3 & postural control
7. #1 & measurement tools	7. #1 - #3 & motion analysis
8. #1 & measurement tests	8. #1 - #3 & centre/center of pressure

### 2.2.2 Study eligibility

Within search strategy A, studies that reported on children (aged birth to 18 years old) with FASD and gross motor function deficits, as well as how these deficits were tested were included in the scoping review. In search strategy B, studies that used single leg hop/land tests as an objective functional measure of DPS were included. In search strategy A, studies were excluded if they reported on adult populations with FASD and if they examined exclusively fine motor control deficits and the testing thereof in children with FASD. In search strategy B, SLH studies were excluded if the outcome measures or parameters used were not related to DPS, as well as if the upper limit of the included participants' age range exceeded 30 years. This age range exceeded that of the range included in search strategy A so as not to exclude the majority of SLH and DPS studies, which have been conducted on adults. Therefore, this age range would allow for the inclusion of SLH and DPS studies in the review, but the age limit was set at 30 to focus the

review on studies done on children and younger adults. All studies conducted on animals and articles not published in English were excluded.

### **2.2.3 Study selection and data extraction**

The principal reviewer (KM) screened and evaluated titles of all relevant hits retrieved from each database. If titles were relevant to the scoping review objectives the abstracts were then reviewed. Full texts of all relevant abstracts were retrieved and reviewed according to the study eligibility criteria (section 2.2.2). Uncertainty with regards to the inclusion of articles was resolved through discussion with a co-reviewer (YB). Data extraction of all relevant items from the included papers was independently conducted by one reviewer (KM) using an electronic data extraction form in consultation with the co-reviewer (YB) to ensure optimum data extraction and synthesis. Data extracted from papers included the year of publication; population groups; age range of the study population; outcome measures and equipment used and important findings of the studies.

### **2.2.4 Methods of data synthesis and analysis**

Due to the descriptive nature of the scoping review which included two separate areas of study (see Table 2.1 for search strategy A and B), the data extracted from the included papers were not comparable in terms of populations, objectives or methods of measurements and thus the results could not be pooled. Therefore the findings of the review were reported in a narrative form.

## **2.3 Results**

### **2.3.1 Article screening and inclusion**

A total of 7958 hits were retrieved from both search strategies A and B. The article screening process for both search strategies can be found in Figures 2.1a and 2.1b. Of the 29 included articles, nine reported on FAS/FASD and gross motor functioning and 20 articles reported on the use of SLH tests to assess DPS. The articles included from search strategy A will be discussed separately to those of search strategy B. The general characteristics of each study will first be described, followed by a description of the tests, procedures, outcome measures/parameters, measurement equipment and important findings (as applicable).

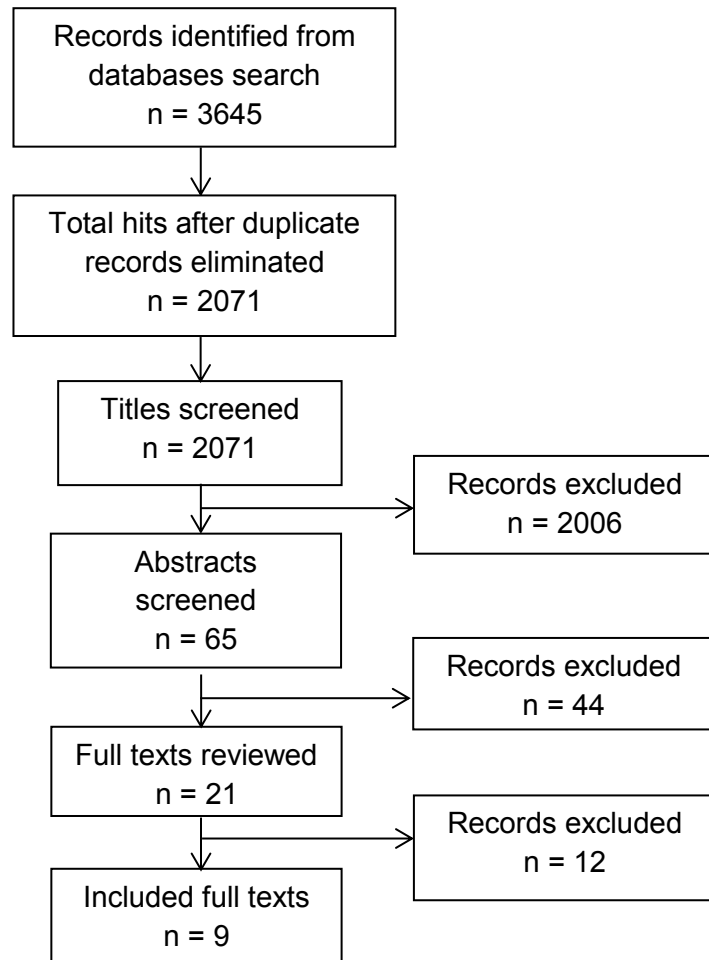


Figure 2.1a Article screening process: Search strategy A

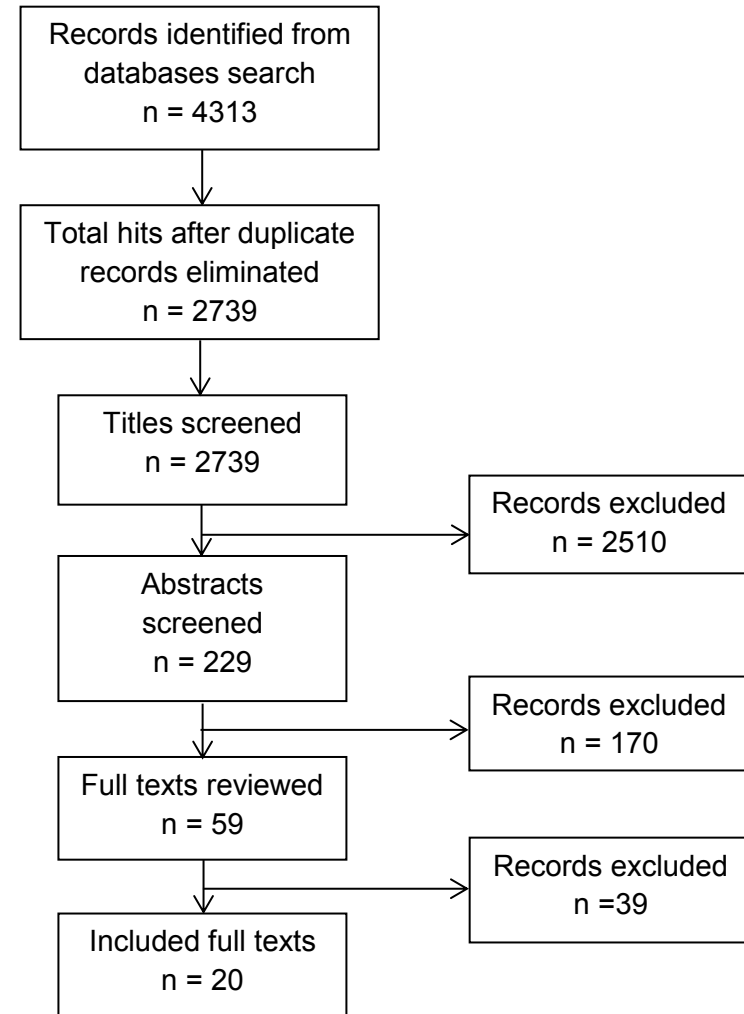


Figure 2.1b Article screening process: Search strategy B

### **2.3.2 Description of studies reporting on gross motor function in children with FASD**

Four studies were conducted in the USA (Barr et al, 1990; Roebuck et al, 1998; Jirikowic et al, 2008; 2013); two studies in Denmark (Kesmodel et al, 2013; Bay et al, 2012); two in South Africa (Davies et al, 2011; Adnams et al, 2001) and one study in Canada (Kooistra et al, 2009). The social demographics of the populations in the studies were inconsistently reported on. Only one study indicated that the research was conducted in rural areas (in South Africa) (Davies et al, 2011). The ages of children recruited in the studies varied from seven months to 16 years old (Kooistra et al, 2009; Barr et al, 1990; Kesmodel et al, 2013; Bay et al, 2012; Roebuck et al, 1998; Jirikowic et al, 2008; 2013; Davies et al, 2011; Adnams et al, 2011). Eight of the nine studies included both male and female children (Kooistra et al, 2009; Kesmodel et al, 2013; Bay et al, 2012; Roebuck et al, 1998; Jirikowic et al, 2008; 2013; Davies et al, 2011; Adnams et al, 2011), while one study conducted by Barr et al (1990) gave no indication of the participants' gender.

The assessment tools used to test motor functioning in children with FASD varied among the papers. Three studies used the MABC (Kooistra et al, 2009; Kesmodel et al, 2013; Bay et al, 2012) and one used the updated version, the MABC-2 (Jirikowic et al, 2013). The remaining studies used other standardised assessment tools namely the Griffiths Mental Development Scale (GMDS) (Davies et al, 2011; Adnams et al, 2001); the BOTMP (Jirikowic et al, 2008), the Clinical Observations of Motor and Postural Skills (COMPS) (Kooistra et al, 2009); the Developmental Neuropsychological Examination (NEPSY) (Jirikowic et al, 2008); the Dynamic Gait Index (DGI) (Jirikowic et al, 2013); the Paediatric Clinical Test of Sensory Interaction



for Balance-2 (P-CTSIB-2) (Jirikowic et al, 2013); the Quick Neurological Screening Test-2 (Jirikowic et al, 2008) and adaptations of balance tests and gross motor assessments (Kooistra et al, 2009; Barr et al, 1990; Roebuck et al, 1998). Three studies used a combination of assessments tools (Kooistra et al, 2009; Jirikowic et al, 2008; 2013). The demographics and motor assessment tools used in each study can be seen in Table 2.2.

Four main areas of motor function assessment were identified among the studies conducted on children with FASD. These were gross motor performance/function; balance control/postural stability; cognitive-motor development and developmental delay; and sensorimotor performance. These main themes will be described in terms of the motor assessment tests, procedures and outcomes measures and important findings.

**Table 2.2 Summary of studies investigating gross motor function in children with FASD**

<b>Study</b>	<b>Country</b>	<b>Age</b>	<b>Gender</b>	<b>Population groups/area</b>	<b>Study objectives</b>	<b>Diagnosis</b>	<b>Motor function assessment</b>
<b>Barr et al 1990</b>	USA	4 years	Not indicated	Predominantly white middle class	Examine fine and gross motor performance in relation to prenatal exposure to alcohol, caffeine, tobacco & Aspirin	457 children prenatally exposed to alcohol, caffeine, tobacco & aspirin	Adapted gross motor battery of tests
<b>Roebuck et al 1998</b>	USA	8-16 years	10 males 14 females	Majority white	Determine whether neuromuscular postural reactions differ in ALC and TD	12 ALC 12 TD	Rapid dorsiflexion movements applied to child standing on force plate
<b>Adnams et al 2001</b>	SA	6-8 years	40 males 28 females	Economically disadvantaged families	Determine cognitive-motor development in children with FAS	34 FAS 34 TD	GMDS
<b>Jirikowic et al 2008</b>	USA	5-8 years	28 males 23 females	Majority of both groups white	Describe sensory processing behaviours and sensorimotor performance	25 FASD 26 TD	1. BOTMP 2. Quick Neurological Screening Test-2 3. Developmental Neuropsychological Examination
<b>Kooistra et al 2009</b>	Canada	7-10 years	68 males 48 females	FASD: 40% low SES ADHD and TD: majority high SES	1. Establish differences in motor performance and examine balance control in children with ADHD and FASD	30 FASD 47 ADHD 39 TD	1. MABC 2. COMPS 3. Static and dynamic balance assessments on force plate

USA: United States of America; SA: South Africa; FASD: Fetal Alcohol Spectrum Disorder; FAS: Fetal Alcohol Syndrome; SES: socioeconomic status; ADHD: Attention Deficit Hyperactivity Disorder; TD: typically developing children; ALC: alcohol exposed; GMDS: Griffiths Mental Development Scale; BOTMP: Bruininks-Oseretsky Test of Motor Proficiency; MABC: Movement Assessment Battery for Children; COMPS: Clinical Observations of Motor and Postural skills

**Table 2.2 Summary of studies investigating gross motor function in children with FASD (continued)**

<b>Study</b>	<b>Country</b>	<b>Age</b>	<b>Gender</b>	<b>Population groups/area</b>	<b>Study objectives</b>	<b>Diagnosis</b>	<b>Motor function assessment</b>
<b>Davies et al 2011</b>	SA	7-29 months	195 males 204 females	Rural areas	Describe extent and nature of developmental delay over 2 time periods (7-12months and 17-29months)	Testing at time1 (7-12months old): 45 FASD; 347 TD Testing at time 2 (17-29months old): 35 FASD; 48 TD	GMDS
<b>Bay et al 2012</b>	Denmark	5 years	354 males 301 females	Not specified	Examine effects of low to moderate alcohol consumption on child motor function	685 children of mothers who reported drinking alcohol during pregnancy	MABC
<b>Jirikowic et al 2013</b>	USA	8-16 years	16 males 4 females	30% of FASD from upper-middle income bracket 100% of TD from upper income bracket	Examine sensorimotor performance and sensory control of balance	10 FASD 10 TD	1.MABC 2. Paediatric Clinical Test of Sensory Interaction for Balance-2 3. DGI 4. MuMBER system
<b>Kesmodel et al 2013</b>	Denmark	5 years	352 males 326 females	Not specified	Examine effects of binge alcohol consumption on child motor function	678 children of mothers who reported drinking alcohol during pregnancy	MABC

SA: South Africa; USA: United States of America; FASD: Fetal Alcohol Spectrum Disorder; TD: typically developing children; GMDS: Griffiths Mental Development Scale; MABC: Movement Assessment Battery for Children; DGI: Dynamic Gait Index; MuMBER: Multi-Modal Balance Entrainment System

### **2.3.2.1 Gross motor performance: Motor assessment tests, procedures and outcome measures**

Four of the nine studies focussed mainly on the assessment of gross motor performance/function (Bay et al, 2012; Kesmodel et al, 2013; Kooistra et al, 2009; Barr et al, 1990).

Bay et al (2012) and Kesmodel et al (2013) used the MABC to test overall motor function. The assessment comprises of eight standardised motor tasks including manual dexterity, ball skills and static and dynamic balance. Specifically for five year old children (the population age in these studies), the gross motor tasks include catching a bean bag, rolling a ball, one leg balance, jumping over a cord and walking with heels raised (Bay et al, 2012; Kesmodel et al, 2013). Physiotherapists, highly trained in utilizing the MABC, performed the motor function assessment. Tasks are scored from 0 to 5 by the examiners according to observation of correctly executed task components (Bay et al, 2012). The total scores thus range from 0 to 40 and higher scores indicate poorer performance (Bay et al, 2012).

Kooistra et al (2009) used the MABC, as well as the COMPS, to test motor function. The COMPS assesses subtle perceptuo-motor problems, focussing specifically on cerebellar function, postural control and motor coordination (Kooistra et al, 2009). The six motor tasks included are slow movements, rapid forearm rotation, finger-to-nose touching, prone extension, supine flexion and asymmetrical tonic neck reflex. Two examiners scored the children on both the MABC and the COMPS. The tasks of the COMPS are scored from 0 to 12 and the sum of the scores are converted to

weighted scores and then corrected for age (Kooistra et al, 2009). Scores less than zero indicate motor and postural impairments (Kooistra et al, 2009).

The study conducted by Barr et al (1990) used a battery of motor tasks adapted from the gross motor scale developed at the Crippled Children's Division of the University of Oregon Medical School and incorporated items from the Gesell and the Bayley scales (Barr et al, 1990). The battery consisted of 14 motor tasks in the sections of balance (standing balance, standing on tiptoe, balance beam, walking forward on a line, walking backward on a line); coordination (walking upstairs, walking downstairs, catching and throwing a large ball, catching and throwing a small ball, skipping, running) and distance achieved for the task (jumping, hopping, standing broad jump). The tasks were administered by two psychometrists and were scored on a 2 to 8 point scale from least mature to most mature, or for some tasks, time or distance achieved were scored (Barr et al, 1990).

#### ***2.3.2.2 Balance Control/Postural stability: Balance tasks, procedures and outcome measures***

Balance control was examined in three studies (Roebuck et al, 1998; Kooistra et al, 2009; Jirikowic et al, 2013).

In the study conducted by Roebuck et al (1998), children stood on two mechanically locked force plates that were controlled to rotate upwards to 8 degrees at a rate of 50 degrees/sec. This rapid dorsiflexion has been shown to elicit all three short-, medium-, and long-latency responses in the muscles of the lower leg (Roebuck et al, 1998). These neuromuscular responses were measured by electromyographic

(EMG) electrodes applied to the children's legs and the authors examined the muscle responses in terms of time of onset and variability.

Kooistra et al (2009) also examined EMG data in terms of time of onset, as well as peak EMG amplitude during a balance perturbation task. For this task, children wore a belt attached to a perturbation mechanism. This mechanism dropped a weight and applied a force of 20% of the child's body weight to the belt for 200ms, pulling the child forward. The children were instructed to stand without taking a step when the force was applied, and the EMG electrodes recorded the neuromuscular responses of the legs. A static balance task was also administered where the children stood as motionless as possible on two feet on a force plate for 30 seconds. The authors examined centre of pressure (COP) parameters including mediolateral (ML) and anteroposterior (AP) excursion; and total COP path area. Higher values of COP measures indicate poorer postural stability (Kooistra et al, 2009).

The third study, conducted by Jirikowic et al (2013), examined sensory control of balance using three balance assessments: the P-CTSIB-2; the DGI and the Multi-modal Balance Entrainment System (MuMBER), all administered by an occupational or physical therapist. For the P-CTSIB-2, balance was assessed under six altered sensory conditions (eyes open standing on floor, eyes closed standing on floor, sway-referenced vision via wearing a dome with eyes open standing on floor, and all three visual conditions done while standing on a memory foam block). Lower total scores indicate worse performance (Jirikowic et al, 2013).

The DGI evaluates eight walking tasks with different vestibular challenges. The authors mentioned two examples of the different walking trials: walking while turning the head left to right, and stepping over obstacles but no further indication of the other six trials was given. Lower total scores indicate poorer performance (Jirikowic et al, 2013).

During the MuMBER protocol, children stood on a piece of memory foam on a platform that tilted (vestibular stimulus), faced a screen that displayed moving dots (visual stimulus), and laid the right index finger on a movable pole (somatosensory stimulus). All sensory stimuli were provided in combinations of speed and intensity and the children were instructed to stand and “do whatever felt natural”. The children’s body sway movements were tracked by a motion analysis system. These movements were used to determine the “sensory weighting variables” for each sensory condition. Essentially, these variables were derived from the magnitude of mediolateral body sway at each sensory frequency, divided by all other peaks of body sway at other frequencies. This data indicated to what extent each sensory sub-system contributed to the whole of postural stability (Jirikowic et al, 2013). Two other kinematic postural control variables were also determined in the study, namely the velocity of body sway movements and the total body sway ellipse area.

### ***2.3.2.3 Cognitive-motor development and developmental delay: Motor assessment tasks, procedures and outcomes measures***

Two papers reported on cognitive-motor development and developmental delay in children with FASD (Davies et al, 2011; Adnams et al, 2001).

The GMDS assessment was used in both studies. The subscales within the test include locomotor, personal-social, hearing and speech, eye and hand coordination and performance. Each subscale is scored independently and an overall developmental quotient is derived, with lower scores indicating poorer performance (Adnams et al, 2001; Davies et al, 2011). The locomotor subscale forms the gross motor assessment and the tasks included range from pushing with feet and holding head upright in early infancy, to jumping and skipping in middle childhood (Adnams et al, 2001). No further elaboration of the specific tasks involved in the GMDS was provided in either study.

#### ***2.3.2.4 Sensorimotor performance: Motor assessment tasks, procedures and outcome measures***

Two studies examined sensorimotor performance in children with FASD (Jirikowic et al, 2013; 2008). The study conducted by Jirikowic et al in 2013, which examined sensory control of balance, has been described in detail in section 2.3.2.2.

Jirikowic et al (2008) used three standardised motor assessment tests to evaluate sensorimotor performance, namely the BOTMP, the Quick Neurological Screening Test-2 and the NEPSY. The BOTMP is a survey of general fine and gross motor skills (Jirikowic et al, 2008) and provides an index of motor proficiency and separate measures of both gross and fine motor skills (Flegel & Kolobe, 2002). The motor tasks fall into eight subtests which include running speed and agility, bilateral coordination, strength, balance, upper limb coordination, response speed, upper limb speed and dexterity and visual-motor control (Flegel & Kolobe, 2002). Lower scores on the tasks indicate poorer performance (Jirikowic et al, 2008).



The Quick Neurological Screening Test-2 assesses motor coordination, balance and vestibular function, motor planning, sequencing and spatial organisation and higher scores indicate poorer performance (Jirikowic et al, 2008). The NEPSY includes measures of coordination, visual-motor precision; motor-planning and sequencing; and lower task scores indicate poorer performance (Jirikowic et al, 2008). Each child was administered the tests in the same order by an experienced physiotherapist or occupational therapist. The specific tasks that children had to perform in each assessment were not described in the study.

### ***2.3.2.5 Summary of important findings***

In terms of gross motor performance, Kooistra et al (2009) found that children with Attention Deficit Hyperactivity Disorder (ADHD) and children with FASD scored significantly higher on the MABC and significantly lower on the COMPS compared to controls, indicating impairments of motor and postural skills in children with ADHD and FASD (Kooistra et al, 2009). Conversely, Bay et al (2012) and Kesmodel et al (2013) found no associations between PAE and mean scores on the MABC. The study conducted by Barr et al (1990) identified that of all the exposures examined (caffeine, tobacco, Aspirin and alcohol), alcohol was the strongest predictor of poor gross motor performance.

Poor balance control and postural stability were found in children with FASD as they significantly exceeded the control group on all COP measures during the static balance task in the study by Kooistra et al (2009). During dynamic balance perturbation tasks, Kooistra et al (2009) and Roebuck et al (1998), found no significant differences in short- and medium-latency EMG responses in children with

FASD compared to controls. However, prenatally alcohol exposed children displayed significantly slower long-latency EMG responses compared to controls (Roebuck et al, 1998). Jirikowic and colleagues (2013) found that children with FASD scored significantly lower than controls on the DGI and the P-CTSIB-2, and displayed higher body velocity sway during the MuMBER protocol across all sensory conditions than controls. Thus, children prenatally exposed to alcohol displayed poorer postural stability and more difficulty adapting to sensory stimuli compared to controls (Jirikowic et al, 2013). Similarly, Jirikowic et al (2008) found that children with FASD displayed significantly more difficulty with sensory processing and sensorimotor performance as assessed by the BOTMP, the Quick Neurological Screening Test-2 and the NEPSY than typically developed children.

In terms of overall motor development, contrasting results were found on the gross motor subscale of the GMDS (Davies et al, 2011 and Adnams et al, 2001). Davies et al (2011) found that children with FASD displayed developmental delay compared to the controls, while Adnams et al (2001) found no significant difference in the gross motor performance between children with and without FASD.

### **2.3.3 Current understanding of gross motor function deficits and testing protocols in children with FASD**

Results indicate that children with FASD display poor performance on motor function tests, as well as poor postural stability. Children with FASD made more errors on gross motor function tasks, displayed longer time to correct errors and had poorer balance than children not prenatally exposed to alcohol (Barr et al, 1990). Poor postural stability and difficulty adapting to changing or inaccurate sensory

information was found in children prenatally exposed to alcohol (Jirikowic et al, 2013) and children with FASD more often performed poorly on sensorimotor measures than typically developed children (Jirikowic et al, 2008). This highlights that children with FASD have difficulty integrating and effectively using competing information from the body's orientation systems to perform motor tasks adequately, as well as to maintain balance.

These findings were corroborated by Roebuck et al (1998) in which lower limb EMG responses were tested. This study found that children prenatally exposed to alcohol exhibited delayed and variable long-latency EMG responses during balance perturbations. Short- and medium-latency responses involve spinal reflexes that do not require central processing at the brain (Roebuck et al, 1998). Long-latency responses on the other hand, follow a transcortical pathway and therefore require central processing, and it is this response that serves to stabilise posture (Roebuck et al, 1998). This highlights the possibility that the integration and processing of information from the body's orientation systems occurs at a cerebral level, and thus the motor and postural deficits found in children with FASD are very likely due to damage caused by PAE to the brain (Roebuck et al, 1998).

Overall, there is consensus that children with FASD struggle with more complex, demanding dynamic motor tasks (as opposed to simple static tasks); as well as postural instability (Roebuck et al, 1998; Kooistra et al, 2009; Jirikowic et al, 2013; Jirikowic, 2008). Testing motor function in children with FASD is most commonly done through the use of standardised assessment tools. Several of the papers in this review agree that the assessment tools available for use with children with FASD are

not sensitive enough to detect subtle motor deficits (Davies et al, 2011; Adnams et al, 2011; Barr et al, 1990; Jirikowic et al, 2008, Kesmodel et al, 2013 and Bay et al, 2012). The use of laboratory type assessments, using equipment that allows for a deeper analysis of certain parameters of function, may allow for more specific identification of motor function impairments and therefore can add to the body of literature, as well as lead to the development of specific treatment plans for those affected.

The literature reviewed on gross motor function in children with FASD highlights the need for further research in this field and that research using objective measurement methods to analyse more complex motor tasks may indicate more accurately the potential motor deficits that children with this disorder exhibit. Pinpointing motor impairments and the underlying causes in this population of children may allow for better and more timeous diagnoses, as well as provide the basis on which physiotherapists and occupational therapists may develop successful, evidence-based treatment protocols.

#### **2.3.4 Description of studies reporting on single leg hop tests to describe dynamic postural stability**

Studies using objective measurement methods and motion analysis techniques to investigate motor function in varying populations, commonly examine functional tasks, such as SLH. Hopping is a complex, dynamic motor task that can be analysed to investigate specific motor control or postural stability impairments (Ross & Guskiewicz 2004). Studies included in this review used different hop protocols to examine dynamic stability in various population groups. A summary of the study demographics, aims, protocols and outcome parameters can be found in Table 2.3. Two papers with some participants over the age of 30 years were included due to the mean ages of the participants falling under 30 years. The papers were analysed according to the following sub-headings: hop protocols, measurement equipment, outcome parameters and data processing.

**Table 2.3 Summary of studies describing single leg hop tests which assess dynamic postural stability**

Study Authors (year); Country	Participant age (years)	Aim of study	Hop Protocols			Equipment	Outcome parameters			
			Bilateral jump & SLL	SLD/J	SLH		GRF/ TTS	COP	DPSI	Kinematics
<b>Birmingham (2000)</b> Canada	21-26	Evaluate reliability of lower extremity functional instability measures			√			√		
<b>Wikstrom et al (2004)</b> USA	20-24	Compare effects of fatigue protocols on TTS, GRF & kinematics during a jump landing	√			Force Plate Motion cameras	√			√
<b>Ross et al (2005)</b> USA	19-24	Determine differences during SLJ landings between stable/unstable ankle groups and report on reliability of TTS	√			Force Plate	√			
<b>Wikstrom et al (2005a)</b> USA	18-24	Determine landing protocol & analysis is most effective in detecting DPS	√	√		Force Plate	√			
<b>Wikstrom et al (2005b)</b> USA	19-25	Assess feasibility, reliability and precision of a new measure of DPS	√			Force Plate	√		√	
<b>Myer et al (2006)</b> USA	14-17	Compare effects of training protocols on power, balance and landing force			√	Force Plate		√		
<b>Wikstrom et al (2007)</b> USA	19-23	Determine whether DPSI could differentiate between those with stable ankles and those FAI	√			Force Plate			√	
<b>Gerbino et al (2007)</b> USA	18-21	Compare balance between dancers and hockey players			√	Pressure mat		√		
<b>Wikstrom et al (2008)</b> USA	18-25	Determine DPS differences among SLH protocols	√			Force Plate			√	
<b>Ross et. al (2009)</b> USA	19-23	Identify most accurate measures to discriminate between stable and unstable ankles	√			Force Plate	√	√		
<b>Brazen et al (2010)</b> USA	17-24	Examine effect of fatigue on landing biomechanics in SLD landings		√		Force Plate Motion cameras	√			√

USA: United States of America; SLL: single leg land; SLD/J: single leg drop/jump; SLH: single leg hop; GRF: ground reaction forces; TTS: time to stability; DPSI: dynamic postural stability index; DPS: dynamic postural stability; FAI: functional ankle instability

**Table 2.3 Summary of studies describing single leg hop tests which assess dynamic postural stability (continued)**

Study Authors (year); Country	Participant age (years)	Aim of study	Hop Protocols			Equipment	Outcome parameters			
			Bilateral jump & SLL	SLD/J	SLH		GRF/ TTS	COP	DPSI	Kinematics
<b>Gribble &amp; Robinson (2010)</b> USA	18-26	Examine lower extremity kinematics during assessment of dynamic stability in CAI	√			Force Plate EMTS	√			√
<b>DiStefano et al (2010)</b> USA	9-11	Compare effects of different training programs on balance and performance measures			√	Force Plate	√			
<b>Steib et al (2013)</b> Germany	19-28	Investigate effect of fatiguing exercise on sensorimotor control in athletes with and without FAI			√	Force Plate	√			
<b>Kuni et al (2014)</b> Germany	16-31 (HPA) 20-28 (RAS)	Analyse the influence of fatigue on DPS in jump-landing and stabilisation	√			Force Plate	√			
<b>Pau et al (2015)</b> Italy	14-16 18-34 (professional group)	Assess existence of correlations between static and dynamic abilities in young and professional elite soccer players	√			Force Plate	√	√		
<b>De Ridder et al (2015a)</b> Belgium	19-25	Evaluate effect of taping on DPS during jump landing protocol in subjects with chronic ankle instability	√			Force Plate Motion cameras			√	√
<b>De Ridder et al (2015b)</b> Belgium	19-27	Establish presence of postural deficits in chronic ankle instability & assess effect of 8 week balance training program on dynamic postural control		√		Force Plate			√	
<b>Heinbaugh et al (2015)</b> USA	19-27	Investigate time-of-day on static and dynamic balance	√			Force Plate			√	
<b>Dallinga et al (2016)</b> Netherlands	18-26	Evaluate DPSI differences between males and females for different jump directions	√			Force Plate			√	

USA: United States of America; SLL: single leg land; SLD/J: single leg drop/jump; SLH: single leg hop; GRF: ground reaction forces; TTS: time to stability; DPSI: dynamic postural stability index; DPS: dynamic postural stability; CAI: chronic ankle instability; FAI: functional ankle instability

### **2.3.4.1 Hop protocols**

Thirteen papers reported on protocols where participants performed a bilateral jump to a certain height (50%-55% of the participant's maximum vertical jump height), over a certain distance, and land on one leg on a force plate (Ross et al, 2009; Wikstrom et al, 2004; 2005a; 2005b; 2007; 2008; Ross et al, 2005; Heinbaugh et al, 2015; Dallinga et al, 2016; Pau et al, 2015; Kuni et al, 2014; De Ridder et al, 2015a; Gribble & Robinson, 2010). Participants stabilised as quickly as possible on the landing leg and maintained stability for a number of seconds. This time varied from no stipulated time to maintain balance (Wikstrom et al, 2004; Pau et al, 2015), to three seconds (Wikstrom et al, 2008; Dallinga et al, 2016; Kuni et al, 2014), to five seconds (De Ridder et al, 2015a; Gribble & Robinson, 2010), to 10 seconds (Wikstrom et al, 2007; Wikstrom et al, 2005b) and finally to 20 seconds (Ross et al, 2009; Wikstrom et al, 2005a; Ross et al, 2005; Heinbaugh et al, 2015). One of these studies used two hop protocols in their testing procedure; the bilateral jump as described above and the single leg drop/jump (Wikstrom et al, 2005a).

Single leg drop/jump protocols were used in three studies (Wikstrom et al, 2005a; Brazen et al, 2010; De Ridder et al, 2015b) where participants stepped, dropped or jumped off a platform of a certain height with one leg and landed on a force plate. They then stabilised and maintained balance on the landing leg for a certain time period. This time period varied from no stipulated time (Brazen et al, 2010), to three seconds (De Ridder et al, 2015b), to 20 seconds (Wikstrom et al, 2005a).

Single leg hop protocols were used in five papers (Birmingham, 2000; Myer et al, 2006; Steib et al, 2013; DiStefano et al, 2010; Gerbino et al, 2007). In four of the



studies participants performed one hop over a certain distance to land and stabilise on one leg on a force plate. In the study by Gerbino et al (2007) participants took two steps and then hopped to land on one leg on the pressure mat. The time the participants had to maintain single leg balance after the land varied from no indicated time (Steib et al, 2013; DiStefano et al, 2010) to 10 seconds (Birmingham, 2000; Myer et al, 2006; Gerbino et al, 2007).

#### ***2.3.4.2 Measurement equipment***

Nineteen studies used a force plate to collect data during the landing phase of the protocol and one study used a Matscan pressure mat (Gerbino et al, 2007). Different force plates were used across the 19 studies and the data was processed using different computer software programs. In addition to the force plate, three studies used motion cameras (Wikstrom et al, 2004; Brazen et al, 2010; De Ridder et al, 2015a) and one study (Gribble & Robinson, 2010) used an electromagnetic tracking system to collect kinematic data.

#### ***2.3.4.3 Outcome parameters and data processing***

The outcome parameters used to determine DPS when landing varied across the studies.

##### ***2.3.4.3.1 Ground reaction force (GRF) and time to stability (TTS)***

Eleven studies used GRF data in the (AP), (ML) and vertical (V) directions to determine TTS of subjects after landing on one leg (Ross et al, 2005; 2009; Wikstrom et al, 2004; 2005a; 2005b; Brazen et al, 2010; Pau et al, 2015; Steib et al,

2013; Kuni et al, 2014; Gribble & Robinson, 2010; DiStefano et al, 2010). TTS data was most commonly reported as the time it takes the GRF components in each direction to reach similar values of those at quiet single leg stance. Three methods of calculating TTS were found in the studies.

The sequential estimation (SE) method was used in six of the studies (Wikstrom et al, 2004; 2005a; 2005b; Brazen et al, 2010; Pau et al, 2015; Gribble & Robinson, 2010). In this method the sequential average of each GRF signal is computed and TTS is achieved when the sequential average remains within 0.25 SD of the overall GRF mean for the complete trial length, or if the GRF components remain within 5% of the average variation of GRF components during quiet stance.

The second method, referred to as the “vibration magnitude curve-fit time to stability” or the unbound third-order polynomial (UTOP) method, was used in five studies (Ross et al, 2005; 2009; Wikstrom et al, 2005a; Steib et al, 2013; DiStefano et al, 2010). In this method the smallest recorded GRF in the AP and ML directions are considered the optimal range of variation values for each direction. These components are rectified and fit with an unbounded third order polynomial and the TTS is the time where the polynomial transects the range of variation reference.

The third method of calculating TTS was used in one study (Kuni et al, 2014). Dynamic postural control was measured as the integrals of the absolute values of GRF in the AP, ML and V directions as functions over time, body mass and gravitational constant. This method gave the authors what they termed the “stabilisation force integral index” (Kuni et al, 2014).

GRF data was used to calculate directional stability indices, rather than TTS in seven studies (Wikstrom et al, 2005b; 2007; 2008; Heinbaugh et al, 2015; Dallinga et al, 2016; De Ridder et al, 2015a; 2015b). ML, AP and V stability indices reflect fluctuations of movement around a zero point. Smaller deviations from the zero point indicate better postural stability. Each directional stability index is then used to calculate the overall composite of the dynamic postural stability index (DPSI)

#### 2.3.4.3.2 Centre of pressure (COP)

Four studies examined COP parameters to determine dynamic stability and each study focussed on varying aspects of COP. Included parameters were COP path lengths (Birmingham 2000; Pau et al, 2015; Gerbino et al, 2007); standard deviations (SD) of COP movement in AP and ML directions (Ross et al, 2009; Myer et al, 2005); COP sway area (Ross et al, 2009; Pau et al 2015; Gerbino et al, 2007); COP maximum AP and ML excursions/displacements (Ross et al, 2009; Pau et al 2015) and COP sway velocity (Ross et al, 2009; Gerbino et al, 2007). Gerbino et al (2007) also used COP to determine the “centre acquisition time” (CAT). This measure is similar to TTS and is used to determine the ability to stabilise. The authors defined the “centre” as a COP sway of less than 5 sensels (the sensory elements of the pressure mat) around one point during a three second period.

#### 2.3.4.3.3 Kinematic parameters

Four studies examined kinematics during single leg hopping/landing (Wikstrom et al, 2004; Brazen et al, 2010; De Ridder et al, 2015a; Gribble & Robinson, 2010). The kinematic parameters included sagittal and frontal plane ankle, knee and hip range

of motion (ROM) (Wikstrom et al, 2004; Brazen et al, 2010; De Ridder et al, 2015a; Gribble & Robinson, 2010).

### **2.3.5 Current understanding of single leg hop tests to assess dynamic postural stability**

Single leg hop testing has been established as suitable for identifying DPS deficits (Ross et al, 2009; Wikstrom et al, 2005a). This is due to the fact that hopping and stabilising on one leg from a land is a complex dynamic task that requires strength, coordination, balance and postural stability (Wikstrom et al, 2004). DPS has been defined as the maintenance of upright balance while transitioning from a dynamic to a static state (De Ridder et al, 2015a). This type of dynamic, challenging test has been found to better relate to true functional performance in different populations than other less complex, static tests such as standing balance tests with eyes open/closed on stable or foam surfaces (Birmingham, 2000).

The most commonly investigated outcome parameters used in these tests to determine DPS during landing from a hop are GRF to determine TTS or DPSI and COP parameters. COP, GRF and TTS parameters measure how well an individual can decelerate the body's centre of mass (COM) and then control the oscillation of the COM on the stabilising leg (Wikstrom et al, 2008). TTS and COP sway have been found to represent spatiotemporal aspects of dynamic postural control and are thus considered appropriate outcome parameters for detecting impairments of dynamic stability (Zech et al, 2015). Thus the outcome parameters used to determine stability during landing from a hop measure the amount and speed of

movement (of either GRF or COP) and the time it takes these parameters to stabilise and remain within values similar to that of static stance.

Kinematic parameters are also used to determine dynamic stability during landing and these include hip, knee and ankle ROM in the sagittal plane. There are contrasting theories with regards to the interpretation of the joint angles during landing from a hop and how they are seen to influence dynamic stability. In one study included in this review, the healthy population landed with increased knee flexion angles. This appears to reflect better landing dynamic stability as the body's COM is controlled in a lower position. In this position the body is less likely to move uncontrollably and is therefore more stable (Gribble & Robinson, 2010).

In contrast to this theory, one study evaluating dynamic stability post-fatigue, found that subjects landed with increased knee flexion after a fatiguing protocol, and this was interpreted to indicate poorer dynamic stability as the muscles were no longer able to maintain postural stability (Brazen et al, 2010). These types of contrasts in the analysis, reporting and interpretation of stability parameters are common in research as authors apply theories and parameters to different populations. This should be taken into consideration in future research and inferences made with regards to landing stability and overall dynamic postural stability should be relevant to the population of interest.

### **2.3.6 Conclusion**

This review identified firstly, that dynamic postural instability is a common gross motor deficit in children with FASD and therefore should be researched in more depth in this population. Secondly, it highlighted the possibility that using objective measures to evaluate motor impairments may be more helpful when examining motor function in children with FASD than merely observer-rated assessment tools. Thirdly, the SLH test was identified as commonly used to examine postural instabilities and movement disorders, and although the protocols of these tests vary considerably, the main outcome parameters of GRF, COP and kinematic data should be analysed to describe DPS during this task.

Therefore, investigating spatiotemporal, kinematic and COP parameters during consecutive SLH to land and stabilise may provide more insight into the movement patterns and overall postural control of children with FASD, thereby adding to the body of available literature.

## **Chapter 3**

### **METHODOLOGY**

This chapter reports on the methodological procedures implemented in both 2014 and 2016 pilot studies. The study completed in 2014 (the rural study) was conducted in Robertson in the WC and included children with and without FASD. The urban study (completed in 2016) was conducted in the Cape metropole and included typically developed children.

#### **3.1 Study aim**

The aim of the study is to describe DPS during SLH in nine-year-old children with and without FASD from a rural area and in nine-year-old typically developed children from an urban area and to determine if any differences exist between the groups of children.

#### **3.2 Research questions**

- 3.2.1 How do nine-year-old children with and without FASD perform a SLH and landing task in terms of DPS (spatiotemporal and COP parameters) and kinematics?
- 3.2.2 Is there a difference in the DPS and kinematics during a SLH and landing task of nine-year-old children diagnosed with FASD compared to typically developed children in rural and urban areas?

### **3.3 Study objectives**

#### **3.3.1 Primary objectives**

- 3.3.1.1 To describe the spatiotemporal parameters during the movement phase of a SLH task in two groups of typically developed nine-year-old children (one urban and one rural) and a group of nine-year-old children diagnosed with FASD.
- 3.3.1.2 To describe the COP parameters and TTS during the landing phase of a SLH task in two groups of typically developed nine-year-old children (one urban and one rural) and a group of nine-year-old children diagnosed with FASD.
- 3.3.1.3 To determine whether any differences exist in spatiotemporal parameters during the movement phase of a SLH task between two groups of typically developed nine-year-old children (one urban and one rural) and a group of nine-year-old children diagnosed with FASD.
- 3.3.1.4 To determine whether any differences exist in the COP parameters and TTS during the landing phase of a SLH task between two groups of typically developed nine-year-old children (one urban and one rural) and a group of nine-year-old children diagnosed with FASD.



### **3.3.2 Secondary objectives**

Since describing joint kinematics during SLH was not a primary objective during the rural study data collection in 2014, joint kinematics was also considered a secondary objective for this study.

3.3.2.1 To describe the kinematics of the hip, knee and ankle joints in the sagittal plane during the movement phase (hopping kinematics) of a SLH task in two groups of typically developed children (one urban and one rural) and a group of children diagnosed with FASD.

3.3.2.2 To describe the kinematics of the hip, knee and ankle joints in the sagittal plane during the landing phase (landing kinematics) of a SLH task in two groups of typically developed children (one urban and one rural) and a group of children diagnosed with FASD.

3.3.2.3 To determine whether any differences exist in the hopping and landing kinematics of the hip, knee and ankle kinematics during a SLH task between two groups of typically developed nine-year-old children (one urban and one rural) and a group of nine-year-old children diagnosed with FASD.

### **3.4 Study design**

A descriptive study with an analytical component using historical case and control groups was conducted.

### **3.5 Study location**

#### **3.5.1 Rural study**

The rural study was conducted in Robertson in the WC in 2014. This setting was selected due to the high prevalence of FASD in this region and because it is an official FASD research site for a large collaborative National Institutes of Health (NIH) research project which incorporates international and local researchers.

#### **3.5.2 Urban study**

The urban study was conducted in the Cape metropole, within the four school districts: Metro North, Metro Central, Metro South and Metro East.

### **3.6 Study population**

#### **3.6.1 Rural study**

The population of the rural study consisted of nine-year-old boys and girls attending primary schools in the rural town of Robertson, or attending surrounding farm schools, either diagnosed with FASD (cases) or with no PAE (controls). The farm schools were situated within a 10km radius of the town. The FASD and no PAE diagnoses were based on the diagnostic procedures described by May et al (2013) who previously screened these grade one learners when they were six years of age. The age group was conveniently chosen because, at the time of the study (2014), most of the screened children would have reached the age of nine years.

### **3.6.2 Urban study**

The urban study population included nine-year-old typically developed children from the Cape metropole. This population was chosen for its close geographical proximity and to represent children from an urban setting of this age group, thus also expanding the normative dataset for the gross motor task of SLH in children in the WC.

## **3.7 Sampling method**

### **3.7.1 Rural study**

The names of all nine-year-old boys and girls, enrolled in three town schools and four farm schools, who were previously screened for FASD and captured on the research database of the study conducted in 2011 (May et al, 2013) were obtained for recruitment for the rural study. The Western Cape Education Department (WCED) gave permission to the rural study principal investigator (PI) (Dr Y. Brink) for the study to be conducted within these primary schools in Robertson (Addendum C). After permission was granted, the principals of the schools were given an information leaflet. Once the principals had consented to participation the recruited children and their parents were given written informed assent and consent forms and the rural study PI made contact with them to discuss the study and answer any questions. The sampling procedure aimed for the inclusion of at least 12 children (cases) from any of the three diagnostic categories of FASD: ARND, PFAS and FAS; and 12 control children with no PAE. An equal distribution of boys ( $n=12$ ) and girls ( $n=12$ ) was sought.

### **3.7.2 Urban study**

The WCED gave permission to the urban study PI (Keryn Moore) for the study to be conducted within primary schools in the four school districts of the Cape metropole. The letter of approval for the study can be found in Addendum D. Primary schools with more than 30 pupils in Grade 3 were eligible for selection. Unisex schools and schools with foreign languages of instruction were excluded. The schools were pooled together in lists for each district, randomised and recruitment began from the top of each list. If the urban study PI was unable to contact a school or if the school declined to participate in the study the next school on the randomised list was contacted. Four primary schools, one from each school district, were selected according to this process.

Principals of the schools were given an information leaflet and consent form (Addendum E) and a meeting was arranged to discuss the study in further detail. A list of nine-year-old children was obtained from each school and the names on each list were randomised. The first 20 children per list were recruited. The teachers of the respective children were given an envelope for each child containing the parent consent form, the child assent form and the health questionnaire (Addenda F; G and H). The health questionnaire included questions regarding maternal behaviour (ie. smoking and drinking), birth history and development of the child. It aimed at identifying any children with abnormal birth history or development, or children that may have been prenatally exposed to alcohol.

### **3.8. Sample size calculation**

No sample size calculation was performed for the rural study as all eligible children were invited to participate in the study. A sample size of 30 children were considered appropriate for the urban study as this sample size was based on observational, biomechanical research conducted by Baker et al (2014). Normative gait research indicated that a sample of at least 30 children is required to have 95% confidence that the true standard deviation (SD) falls within 2° of the measured SD (Baker et al, 2014).

### **3.9 Inclusion criteria**

#### **3.9.1 Rural study**

Nine-year-old learners diagnosed (at the age of six years) with ARND, PFAS or FAS for the case group, or no PAE and no history of developmental or neurological disorders for the control group, who were still attending one of the seven selected primary schools and from whom parental/guardian written informed consent and child written informed assent were obtained, were eligible to participate.

#### **3.9.2 Urban study**

Typically developed nine-year-old learners, with no history of developmental or neurological disorders, enrolled in the participating schools, and from whom parental/guardian written informed consent and child written informed assent were obtained, were eligible to participate.

### **3.10 Exclusion criteria**

#### **3.10.1 Rural study**

Children diagnosed with neurological, musculoskeletal or movement disorders other than those associated with PAE were excluded (e.g. Attention Deficit Disorders and Developmental Coordination Disorder) (Kooistra et al, 2009). The group of researchers (May et al, 2013) who diagnosed the children at six years old collected data through interviews with the learners' parents and teachers with regards to the children's health and the presence of any neurological, musculoskeletal or movement disorders. At the time of the rural study in 2014, no further paediatric assessments were conducted, however children would have been potentially excluded from the study if any neurological, musculoskeletal or movement disorders had been reported by May et al (2013).

#### **3.10.2 Urban study**

Children of mothers who indicated alcohol consumption during pregnancy on the health questionnaire; children with any diagnosis of developmental delay; or children who measured below the 10<sup>th</sup> percentile for age and gender on measurements of height, weight, and occipital frontal circumference (OFC) (Addendum I), were excluded. Children with any musculoskeletal pain or injury at the time of testing were also excluded from the study.

### **3.11 Movement task (single leg hopping)**

The participants hopped consecutively on one leg in each of five conjoined squares and after the last square landed on a pressure mat with the foot as straight as

possible and maintained balance on the same leg. In the rural study, the instruction given was to maintain balance for three seconds; whereas in the urban study it was stipulated that the children maintain balance for five seconds, until the urban study PI signalled that they could step off the pressure mat. This task comprised of two phases: the movement phase, where the child completed five hops in a row; and the landing phase where the child landed and maintained balance on the pressure mat. The participants were instructed to hop only once in each block and without touching the borders of the square. Upper limb movement was not restricted during the task.

### **3.12 Measurement instrumentation**

#### **3.12.1 Height and weight measurement**

Height was measured with a wall-mounted tape measure and weight was measured using a calibrated, digital scale in both rural and urban studies.

#### **3.12.2 Occipital frontal circumference measurement**

The OFC was measured using a flexible, non-elastic tape measure in the urban study.

#### **3.12.3 Xsens MTw wireless motion trackers**

In the rural study the Xsens MTw wireless motion system (Xsens MTw, B.V. Technologies, Enschede, Netherlands) was used to measure spatiotemporal and joint kinematics. The Xsens MTw motion trackers are wireless, inertial and magnetic sensors which provide 3D orientation, acceleration and angular velocity data of

human movement and provide whole-body kinematic measurement (Zhang et al, 2013). The system is highly accurate in describing human motion in research and clinical settings (Zhou 2008; Saber Sheikh 2010; Guo 2013) and is reliable for use outside of a laboratory as lower limb sagittal plane kinematics have been found to be comparable to that of the VICON system (Oxford metric group, Oxford) (Cloete & Scheffer, 2008). Cloete and Scheffer (2008) found mean correlation coefficients of the two systems for hip and knee flexion/extension of 0.94 and 0.89 respectively.

#### **3.12.4 Tekscan Conformat pressure mat**

The Tekscan Conformat (Matscan, Tekscan Inc.) was used in both the rural and urban studies during the landing phase of the SLH task. The Tekscan pressure mat is a portable dynamic pressure mapping device which is designed to measure plantar pressure distribution and movement (Brenton-Rule et al, 2012). The Tekscan software allows for real-time as well as offline viewing of the data, and has several processing and plotting features, including the calculation of the COP position on the mat. The instrument is valid and reliable for measuring plantar pressure distributions (Zammit et al, 2010; Brenton-Rule et al, 2012; Hafer et al, 2013).

#### **3.12.5 Noraxon MyoMotion System**

The Noraxon MyoMotion (Noraxon, U.S.A, Inc.) was used to measure spatiotemporal parameters and kinematics in the urban study. The MyoMotion system is comprised of compact, portable inertial measurement units (IMU) which enable the tracking of 3D angular orientation of body segments and joint ROM. The instrument is valid and comparable to the VICON system (VICON, Oxford metric



group, Oxford) A correlation coefficient as high as 0.99 between the MyoMotion and the VICON systems for dynamic trials has been reported in a study by Balasubramanian (2013). The MyoMotion system was chosen for the urban study as it is more sophisticated and operator-friendly compared to the Xsens system.

### **3.12.6 Concurrent validity testing**

Due to the change in measurement instruments between the rural and urban studies for capturing spatiotemporal and joint kinematic parameters, a concurrent validity testing procedure was performed to determine the measurement agreement between the Xsens and MyoMotion systems (described in section 3.14.7).

### **3.13 Outcome parameters for dynamic postural stability and kinematics**

#### **3.13.1 Spatiotemporal parameters**

The single leg hops were described in terms of individual hop cycles. Each hop was considered from foot contact in one block until foot contact in the next block and was separated into two phases: stance phase and swing phase. The spatiotemporal parameters include:

- 1.) Stance time (s); time between foot contact and toe-off;
- 2.) Swing time (s); time between toe-off and foot contact;
- 3.) Speed of complete trial ( $\text{m}\cdot\text{s}^{-1}$ ); speed of all hop cycles combined, from the first foot contact to the last foot contact on the pressure mat. Speed was calculated by dividing the distance of the hopping trial (1.8m) by the total trial time (s).

These measurements are adaptations of parameters used during 3D gait analysis in a study by Bugaré et al (2012).

#### **3.13.2 Centre of pressure parameters and time to stability**

Four COP parameters, AP and ML COP ROM and the mean COP velocity in the AP ( $\text{AP}_{\text{vel}}$ ) and ML ( $\text{ML}_{\text{vel}}$ ) directions, were captured during the landing phase of the final SLH onto the pressure mat (Birmingham, 2000; Myer et al, 2006; Pau et al, 2015). TTS was calculated using a custom Matlab algorithm adapted from the methods used for force plate analysis of TTS (refer to section 3.16).

### **3.13.3 Kinematics**

The kinematic parameters included maximum and minimum angles and ROM of the hip, knee and ankle joints in the sagittal plane during the movement phase of SLH. Angle at initial foot contact (IFC) and maximum hip, knee and ankle angles in the sagittal plane were identified during the landing phase of SLH on the pressure mat (Caulfield & Garrett, 2002; Decker et al, 2003; Delahunt et al, 2006).

### **3.14 Procedure**

The procedure of the urban study replicated the procedure used in the rural study.

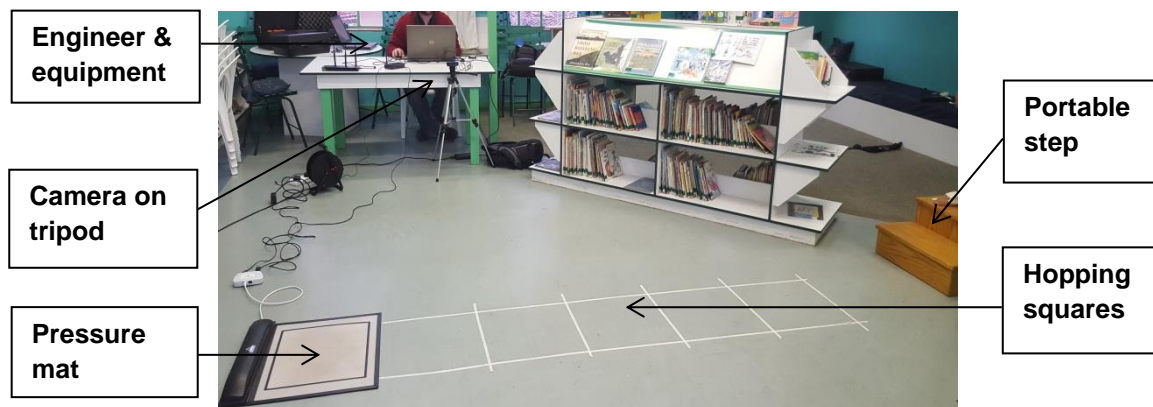
#### **3.14.1 Sampling of participants**

In both rural and urban studies, permission was granted by the WCED to conduct the studies in the respective areas. The principals of the selected schools gave informed written or verbal consent and thereafter written informed consent was obtained from the recruited participants and their parent/guardian during March/April 2014 for the rural study and during March/April 2016 for the urban study. The researchers (the rural study PI in 2014 and the urban study PI in 2016) contacted the parents/guardians telephonically or via the school principals to allow the parents and participants the opportunity to ask questions relating to the research procedure.

#### **3.14.2 Preparation of the venue and equipment setup**

Quiet and private venues were chosen at the schools for data collection in both the rural and the urban studies. School halls, libraries and classrooms were used, depending on the available space. In all schools included in both the rural and urban studies, venues with hard floors were chosen for the testing area so as to try and

keep it as standardised as possible. Each venue was set up with a height, weight and OFC measurement station, the SLH task area and the work station for the engineer's equipment as well as a camera mounted on a tripod. An example of the layout of the area can be seen in Figure 3.1. The SLH task area was laid out with five conjoined squares in a line, marked with masking tape, all 45cm by 45cm (according to the MABC "hopping in squares" task setup) (Henderson & Sugden, 1992). The pressure mat was set up at the end of the five squares. A portable step was positioned 0.5m to 1m from the first of the five squares. This was for the children to stand on during calibration and prior to each hopping trial to eliminate any magnetic interference (from the floor or surrounding objects) with the sensor units. The camera mounted on a tripod was positioned perpendicularly to and no less than 2m away from the hopping area to ensure a clear, lateral view of all the squares as well as the pressure mat.



**Figure 3.1 Picture of the layout of the data collection area**

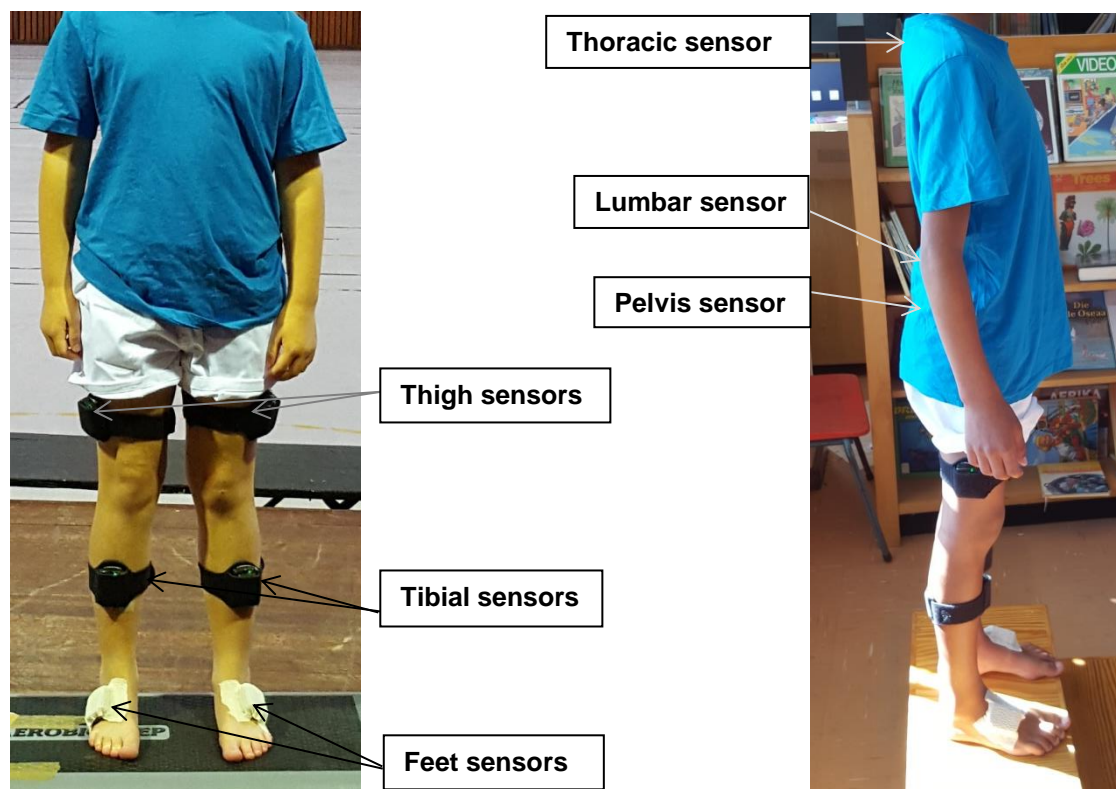
### **3.14.3 Height, weight and occipital frontal circumference measurements**

Each child was brought individually or in pairs to the venue by the rural study PI (in 2014) and the urban study PI (in 2016) or an available staff member who helped the children get changed into shorts and t-shirt and helped with explaining and translating instructions if necessary (the urban study included one school in which the primary medium of instruction was isiXhosa). In both rural and urban studies, the respective PI's took height measurements of each child using a wall-mounted tape measure and weight was measured using a digital calibrated scale. The OFC measurement, taken only in the urban study, was measured using a flexible, non-elastic tape measure, and measured over the frontal skull bones, above the eyebrows and ears and around the most prominent part of the back of the head (the occiput) (National Health And Nutrition Examination Survey, Anthropometry procedures manual, 2007)

#### **3.14.4 Preparing the participant for testing**

The rural and urban study PI's followed the same procedure for preparing the participant. The respective PI explained and demonstrated the task to each child once all measurements had been taken and the child was dressed and ready for testing. The instructions given were that the child must hop on one leg, only once in each block, without touching the lines of the blocks and not putting the other foot down at all during the movement. When landing on the pressure mat at the end of the five blocks they must land with their foot straight, with the toes pointing forwards, and try and "stick" their landing and balance on that leg until the respective PI indicates they can step off the mat. The child was then given the chance to perform practice trials on both legs. Up to three practice trials were allowed when necessary. The child performed all practice trials and the testing barefoot.

Once the child had completed the practice trials, the MyoMotion (in the urban study) or the Xsens (in the rural study) sensor units were placed upon the child using Velcro straps and tape. Figure 3.2 shows the positioning of the sensors on the lower limbs. The rural study PI, having conducted the rural hopping study previously, and the engineer who worked on both the rural and urban studies, trained the urban study PI in sensor placement so as to ensure correct and reliable placement for data collection. In the urban study nine sensors were placed on the body in specific positions: thoracic - T1; lumbar - L3/4; pelvis - sacrum; thighs (bilateral) - mid iliotibial band (ITB); lower legs (bilateral) - mid tibia; feet (bilateral) - proximal-lateral dorsum of the arch of the foot. The rural study also included a sensor placed on the forehead of the participant.



**Figure 3.2 The inertial sensor unit placements**

### **3.14.5 Calibration**

Prior to the first trial, each participant was positioned in a neutral standing position on the wooden step for calibration of the measurement system. The relevant PI helped the child into a neutral position ensuring weight was equally distributed on each leg, the feet straight, the lower limbs in neutral joint position and aligned under the pelvis, the pelvis in natural stance position and the thorax, head and neck upright and aligned with the rest of the body. The participant was instructed to stand as still as possible while the calibration process was completed. The engineer checked the calibration while the child walked the length of the hopping area, or by asking the child to perform hip and knee flexion movements in standing.

### **3.14.6 Single leg hopping task**

Participants were instructed to begin the task on whichever leg he or she felt comfortable to start with and to continue to hop on that leg for each trial until instructed to move onto the other leg. A minimum of three trials was recorded per leg per participant. Between each trial the child was instructed to return to standing on the portable step behind the first block. Trials were unsuccessful if the participant's foot touched the lines of the squares, if they hopped more than once in any of the blocks or if they put the non-weight bearing leg down during the movement or landing phase of the task. If a trial was unsuccessful the task was repeated up to a maximum of three attempts. The respective PI's observed the hopping task to identify any errors, and the engineer checked the quality of the data after each trial.

### **3.14.7 Concurrent validity testing**

Seven children in the urban study were tested with both the MyoMotion and Xsens measurement systems. Once the child had completed all hopping trials with the MyoMotion system, the Xsens sensor units were positioned next to the MyoMotion sensor units on both of the child's feet and the child completed the hopping trials again according to the above procedure. It was not possible to place both sets of sensors on all of the lower limb placements (Figure 3.2) as the securing Velcro straps were too bulky to position the sensors accurately and comfortably on all lower limb placements. Kinematic data could therefore not be captured with both systems simultaneously. Thus only concurrent validity for the spatiotemporal and TTS parameters could be performed. The comparability of the individual systems to the



VICON system was considered sufficient to enable comparison between the two instruments for the joint kinematics parameters.

#### **3.14.8 Time period for data collection at the schools**

One day was allocated per school to conduct the testing in both the rural and urban studies. Each participant took approximately 25 to 30 minutes to complete all the required hopping trials and six to eight children were tested each day. The rural study included seven schools and took five days to complete data collection (twice two schools were captured on one day), and the urban study included four schools and four days were required to complete the data collection process.

#### **3.14.9 Research team and responsibilities**

A research assistant, who had been trained prior to data collection, assisted the PI in the rural study. No research assistant was used in the urban study. In both the rural and urban studies the respective PI took all of the children's measurements, explained and supervised the hopping task and applied the sensor units to the children. The engineer operated the Noraxon MyoMotion system (in the urban study), the Xsens MTw system (in the urban and rural studies) and the Tekscan Conformat pressure mat (in the urban and rural studies). The rural study PI, having completed testing in 2014, before the urban study in 2016, ensured that the urban study PI followed the exact procedure for taking the children's measurements, supervising the hopping task and applying the sensor units to ensure comparability between studies. The engineer collected and monitored the data in both the rural and urban studies and therefore followed the same procedures in both studies.

### **3.15 Data processing**

#### **3.15.1 Height, weight, occipital frontal circumference and body mass index**

The height, weight and OFC data were imported into MS Excel and the body mass index (BMI) was calculated using the formula:  $BMI = \text{kg/m}^2$ . The height, weight and OFC data were used in the urban study on the day of testing to determine whether the children's measurements fell above the 10<sup>th</sup> percentile according to the WHO growth charts (Addendum I).

#### **3.15.2 Single leg hopping trial data**

Data processing of the consecutive SLH task examined in both rural and urban studies was done by the urban study PI (Keryn Moore). The data for all hopping trials (from the rural and urban studies) were imported into the Tekscan Matscan Research 6.80 programme and the Noraxon MyoResearch 3.8 programme on the urban study PI's computer. The video recordings of each hopping trial were examined individually by the urban study PI to ensure the movement phase of the task was successful as per the criteria previously stated in section 3.14.4. The landing phase of each hopping trial was then examined using the Tekscan programme videos to determine whether the landing phase of the task had been performed correctly (according to the criteria stated in section 3.14.4). If multiple trials from the same participant were successful, the first successful trial was chosen for data processing and analysis. One successful hopping trial for both the left and the right lower limbs was chosen for each participant where possible.

The MyoMotion system program records data from the sensor units and processes the data automatically into joint angles throughout the movement. The system enables the engineer to watch and monitor the data being recorded and processed during the hopping trial. This is visible and easy to read, as shown in Figure 3.3.

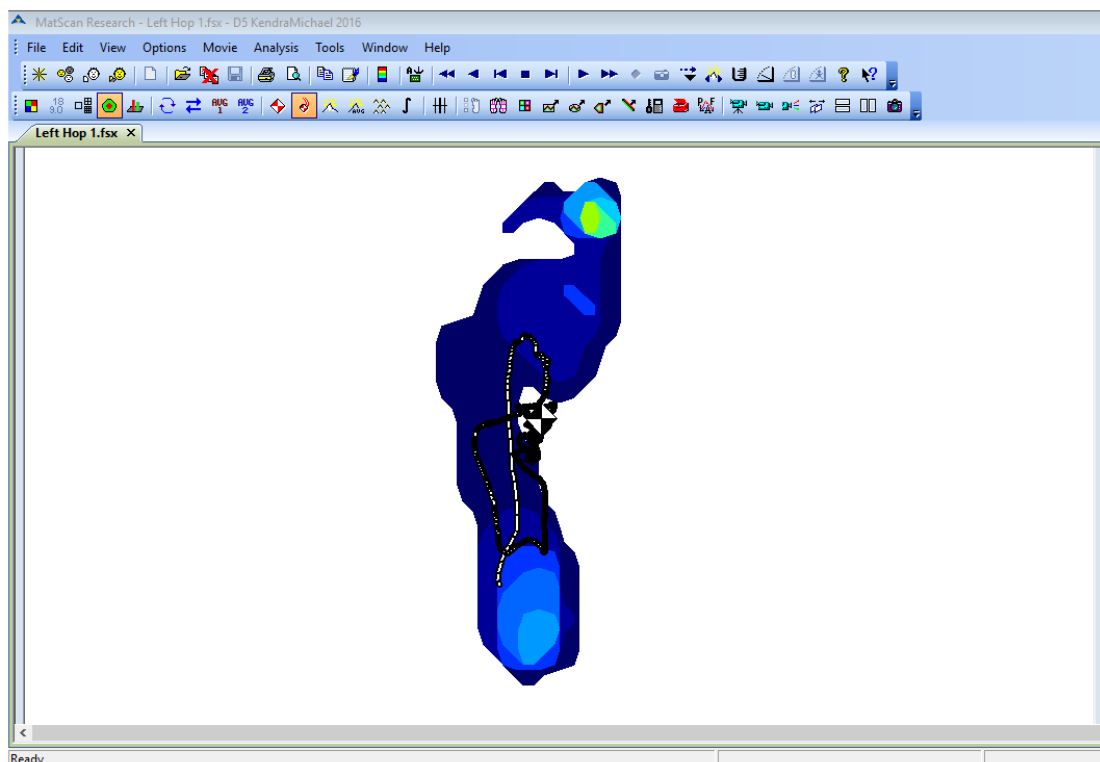


**Figure 3.3** An image of the MyoMotion Research program displaying real time kinematics and sensor movement

The Xsens system recorded raw data which was processed through filters and custom-developed algorithms (developed by the engineer) to compute joint angles. During examination of the rural study's data, the urban study PI and the engineer identified that data from some trials were corrupt due to various reasons. The Xsens system does not allow for monitoring of the sensor signals during the hopping trials to identify any technical problems or magnetic interference which may disturb the

signals from the sensor units to the transmitters. Thus, trials from the rural study had data that were corrupt or lost. This influenced the decision to use the newer MyoMotion measuring system for the urban study, so as to achieve better datasets for the hopping trials.

The Tekscan Matscan software recorded a video for each trial in terms of plantar pressure mapping throughout the landing phase. This video was analysed according to plantar pressure and COP movement (see Figure 3.4). The lighter shades of blue of the foot indicate increased plantar pressure on the mat in these areas. The black and white line indicates the COP path and the black and white square indicates the COP. This successful land shows the foot is straight on the mat and the child has “stuck” the landing correctly on one foot.



**Figure 3.4** An image of the Tekscan pressure mat video

Rotational movements of the foot on the pressure mat causes errors in the COP measurement which renders the true COP AP and ML outcomes unusable. Thus, when selecting hopping trials for inclusion in data processing and analysing, the first criterion to be met was that the foot was aligned straight on the mat. If the position of the foot was correct, the landing phase was then examined and if there was no subsequent rotational movement of the foot on the mat, the COP data was recorded from the time of IFC until the non-weight bearing foot made contact with the mat or up to three - five seconds of recorded Tekscan data. If, however, there was subsequent movement of the foot on the pressure mat after landing, this was termed a “shuffle”. Due to the large amount of trials in which participants shuffled on landing, these trials were not discarded, and all parameters except COP and TTS were included in the data processing and analysis.

Once the successful hopping trials for each leg of each participant were selected by the urban study PI, the data were separated into groups for processing and analysis.

The groups of data were:

1. Rural cases (spatiotemporal, COP and kinematics,);
2. Rural controls (spatiotemporal, COP and kinematics);
3. Urban controls (spatiotemporal, COP and kinematics);
4. Rural cases that shuffled on landing (spatiotemporal and kinematics);
5. Rural controls that shuffled on landing (spatiotemporal and kinematics);
6. Urban controls that shuffled on landing (spatiotemporal and kinematics).

### 3.16 Data reduction

For the movement phase of the task, IFC and foot off events for the Xsens system (rural study and urban validity testing) were detected using a custom Matlab algorithm, adapted from the gait analysis methods which detect event signatures from measured foot kinematics. In the urban study, for the MyoMotion system, IFC and foot off events were detected using the Noraxon MyoResearch contacts algorithm and outliers and false detections were manually corrected using time-synchronized video. A 4<sup>th</sup> order zero-lag low-pass Butterworth filter (cut-off frequency of 8Hz) was used for smoothing of the joint angles for the kinematic outcome parameters.

For the landing phase of the task, IFC onto the pressure mat was determined using a minimum force threshold. A custom Matlab algorithm was used to calculate COP ROM and velocity in the AP and ML directions. TTS was determined using a custom Matlab algorithm adapted from the methods used for force plate analysis of TTS. TTS was the time that the coefficient of variance in the smoothed cumulative force output (root mean square over 250ms) from the pressure mat remained below 5% for at least 500ms. We chose the coefficient of variance as an alternative threshold metric to the percentage force relative to body weight (used in force plate studies) because the pressure platform cannot measure body weight.

### 3.17 Data analysis

Descriptive statistics are presented in median and range values for DPS parameters (spatiotemporal, COP, TTS and kinematic parameters) for the case and control groups, and per gender, as the data were not normally distributed. To determine

whether differences existed for all parameters between the three groups, Kruskal-Wallis tests (for non-parametric data) were conducted; significance level of  $p < 0.05$ . If these tests indicated a statistically significant difference, post hoc Mann-Whitney U tests were conducted to specify between which groups the difference existed; with a significance level of  $p < 0.05$ .

### **3.18 Ethical considerations**

The study was conducted according to the National and International ethical guidelines and principles, including those of the international Declaration of Helsinki October 2013. Ethical approval for this study was obtained from the Health Research Ethics Committee of Stellenbosch University (Addendum J) and approval of the study was provided by the WCED (Addendum D). Principals of the selected schools and parents/guardians of the selected children gave written informed consent prior to the study. The included learners also gave written informed assent prior to participating in the study. The informed consent/assent letters, as well as the health questionnaire, were available in English, Afrikaans and Xhosa. Parents/guardians and participants were informed of the nature of the study and made aware that there will be no consequences for withdrawal from the study. The participants were made aware of the right to withdraw from the study at any time. All personal information of participants was kept confidential and records kept on a password-secured computer. The testing was conducted in a safe, private and quiet venue at each school and the PI (a trained and registered physiotherapist) was present at all times to respond to any emergencies or injuries.

## Chapter 4

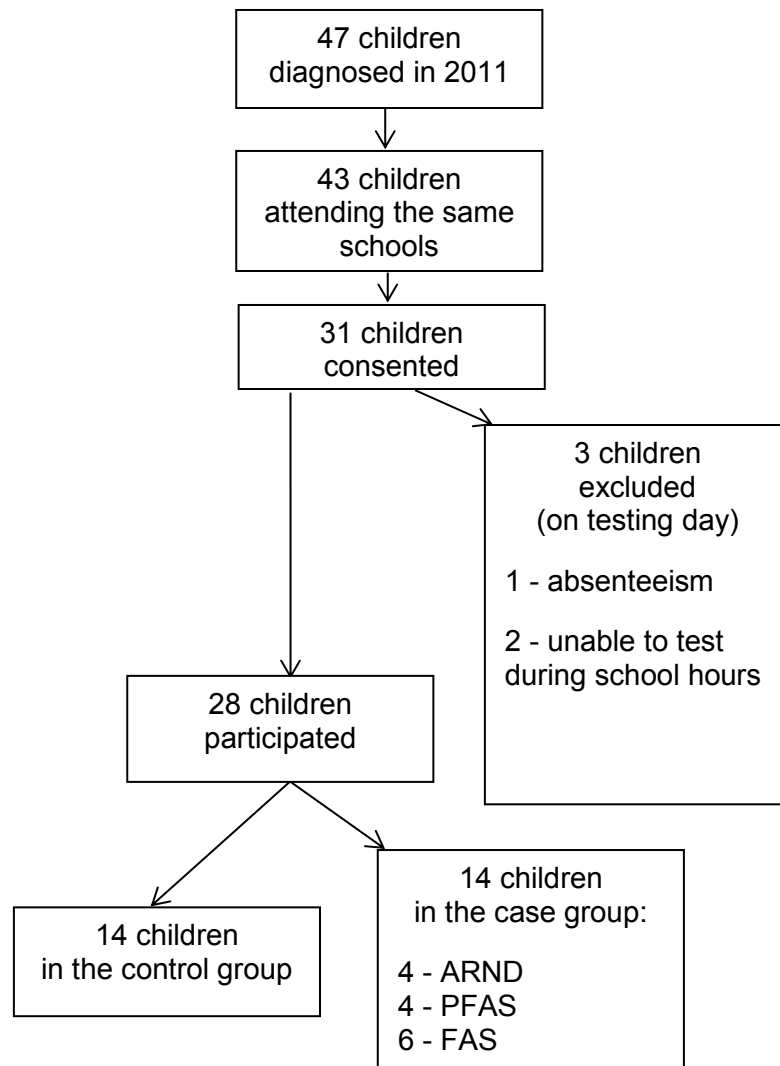
### RESULTS

#### 4.1 Study participants

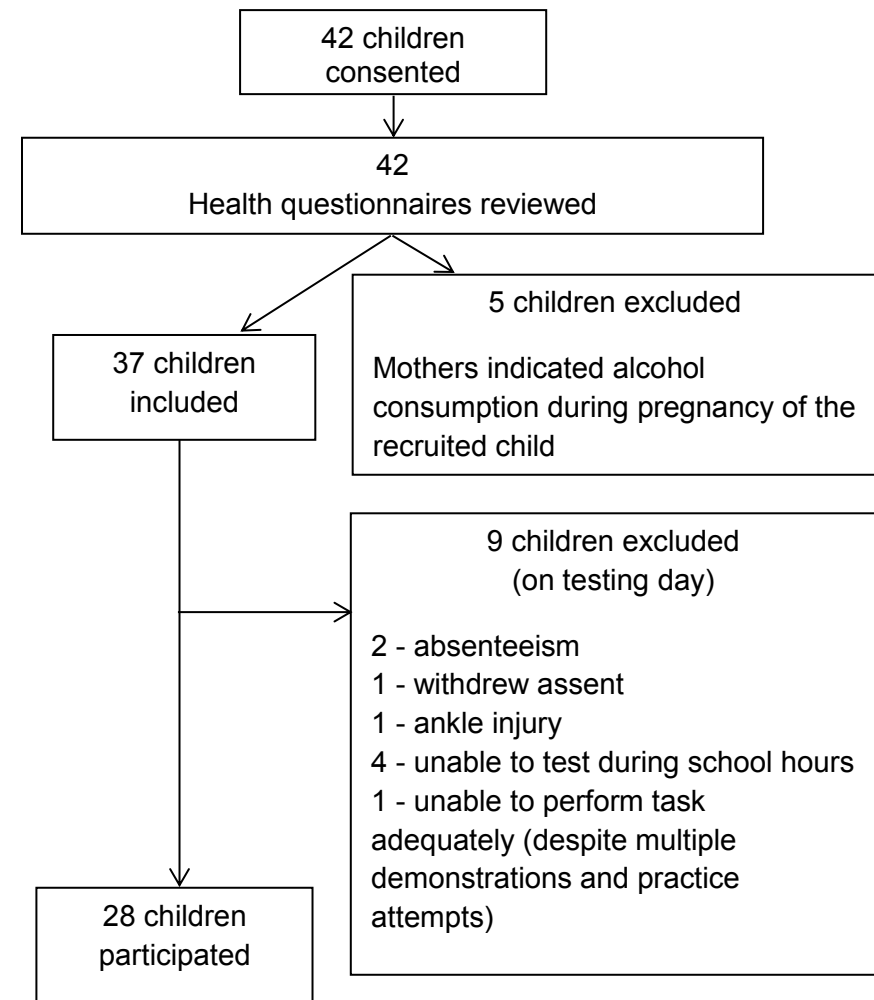
In the rural study, of the 47 children diagnosed when they were six years old (May et al, 2013), 43 (91.5%) were attending the same schools and of those, 31 children (66%) consented to participate in the study. Three children were excluded on the day of testing (see Figure 4.1a). Therefore 28 children, 16 males and 12 females, participated in the study. Fourteen children diagnosed with FAS, PFAS or ARND made up the case group and 14 typically developed children made up the control group. Both groups consisted of eight males and six females. In total, four children with ARND (two males and two females); four with PFAS (two males and two females); six with FAS (four males and two females); and 14 with no PAE (eight males and six females) were assessed.

Forty-two children consented to participate in the urban study and the returned health questionnaires were examined by the PI. Five children were excluded as their mothers indicated they had consumed alcohol during their pregnancies (see Figure 4.1b). None of the returned health questionnaires indicated that any of the participants had been diagnosed with musculoskeletal or neurological disorders (see addendum K for a summary of the sample population's health information acquired through the health questionnaire). No children were excluded due to the height, weight or OFC criteria. Nine children were excluded from the study on the days of testing and therefore 28 children, 13 males and 15 females were tested. The sample selection process for both studies can be seen in Figures 4.1a and 4.1b.





**Figure 4.1a Sample selection process: Rural study**



**Figure 4.1b Sample selection process: Urban study**

ARND: alcohol-related neurodevelopmental disorder; PFAS: partial Fetal Alcohol Syndrome; FAS: Fetal Alcohol Syndrome

## 4.2 Combined sample demographics

Before analysing the demographic data, one male urban control outlier for height, weight and BMI was identified. His measurements were: height (1.58m); weight (74.4kg) and BMI (29.99) and all three of these values fall above the 97<sup>th</sup> percentile on the WHO growth charts (WHO, 2007). Post-hoc exclusion criteria of height, weight and BMI values above the 97<sup>th</sup> percentile were introduced, and the participant was excluded from the urban control group. The sample demographics, for both rural and urban studies, with median and range values for age, height, weight and BMI are presented in table 4.1. The urban control group had significantly higher values for height (males:  $p=0.01$ ; females:  $p=0.02$ ) but not for weight (males:  $p=0.09$ ; females:  $p=0.09$ ) compared to the cases. Median values for BMI across the three groups were similar, all falling between the 50<sup>th</sup> and 97<sup>th</sup> percentiles for BMI according to the World Health Organisation (WHO) BMI-for-age charts (WHO, 2007).

**Table 4.1 The median (range) values for age, height, weight and BMI for the three groups per gender**

	<b>Cases</b>		<b>Rural Controls</b>		<b>Urban Controls</b>	
	<b>n = 14</b>		<b>n = 14</b>		<b>n = 27</b>	
	<b>Males</b> <b>n = 8</b>	<b>Females</b> <b>n = 6</b>	<b>Males</b> <b>n = 8</b>	<b>Females</b> <b>n = 6</b>	<b>Males</b> <b>n = 12</b>	<b>Females</b> <b>n = 15</b>
<b>Age</b>	9 years, 7 months	9 years, 5 months	9 years, 4 months	9 years, 8 months	9 years, 2 months	9 years, 3 months
<b>Height (m)</b>	1.25 (1.09-1.31)	1.26 (1.17-1.34)	1.27 (1.2-1.32)	1.26 (1.22-1.44)	1.31 (1.23-1.45)	1.31 (1.26-1.45)
<b>Weight (kg)</b>	24.85 (20-27.4)	26.5 (20-32.1)	26.3 (24.4-30)	28.35 (23.2-47)	25.85 (23.1-38.6)	30.3 (21.2-41.7)
<b>BMI (kg/m<sup>2</sup>)</b>	16.23 (13.27-18.18)	16.8 (14.61-20.22)	16.88 (14.72-18.61)	18.41 (14.85-22.67)	15.78 (13.64-18.49)	16.85 (13.14-23.6)

n: number of participants; m: metres; kg kilograms; BMI: body mass index

### 4.3 Validity testing of measurement instruments

Concurrent validity testing was done on seven of the 28 children that completed the testing protocol in the urban study to compare the Xsens and MyoMotion measurement systems. The Xsens sensors were placed next to the MyoMotion sensors on the participant's feet, and the task repeated on both legs. Addendum L shows method comparison plots and Bland-Altman plots to show the difference between the systems. On all spatiotemporal parameters (Table 4.2) negligible differences were found between the Xsens and the MyoMotion, and all measures fell within  $\pm 2SD$  of the mean difference between the two system's measures (limits of agreement) (Bland 1990). It is therefore reasonable and valid to compare the Xsens and the MyoMotion systems on spatiotemporal parameters.

**Table 4.2 Bland-Altman limits of agreement between Xsens and MyoMotion measurement systems for spatiotemporal parameters**

	Total trial time (FC1 - FC5)		Swing time		Stance time	
	Left	Right	Left	Right	Left	Right
<b>Mean difference=d</b>	0.00	0.00	-0.04	-0.04	0.03	0.03
<b>Upper limit (UL = d+2SD)</b>	0.02	0.03	0.00	0.00	0.06	0.07
<b>Lower limit (LL = d-2SD)</b>	-0.02	-0.02	-0.07	-0.08	0.00	-0.01
<b>Width (UL-LL)</b>	0.05	0.05	0.07	0.08	0.06	0.08

FC: foot contact; SD: standard deviation

#### 4.4 Excluded trials

In the case group, six of the 28 trials (21.4%) (sum of the left and right legs) were unsuccessful according to the criteria presented in section 3.14.4. Two children (one female and one male) were unable to complete the task successfully in the allowed number of attempts for both left and right legs (four trials); one child (female) could not complete the task successfully for the right leg (one trial) and another child (female) for the left leg (one trial). These trials were not included in the analysis of any of the outcome parameters. All children in both rural and urban control groups could successfully complete the task for both legs. One trial in the case group (male) and two trials (one male and one female) in the rural control group had to be excluded from analysis due to data file corruptions.

In addition to the abovementioned exclusions, one trial in the urban control group (male) had to be excluded due to data file corruptions for spatiotemporal parameters. Six trials in each of the three groups (five male and one female in the case group, three male and three female in the rural control group and two male and four female in the urban control group) had to be excluded from the COP and TTS analysis. These participants shuffled on the pressure mat during landing and the shuffling action changes the AP and ML orientation of the foot on the pressure mat and therefore renders the COP and TTS data unusable.

Ten trials were excluded from the hopping kinematic analysis in the case group (seven male and three female); seven trials in the rural control group (three male and four female) and three trials in the urban controls (two male and one female). These participants either did not have all sensors placed on them or there were technical

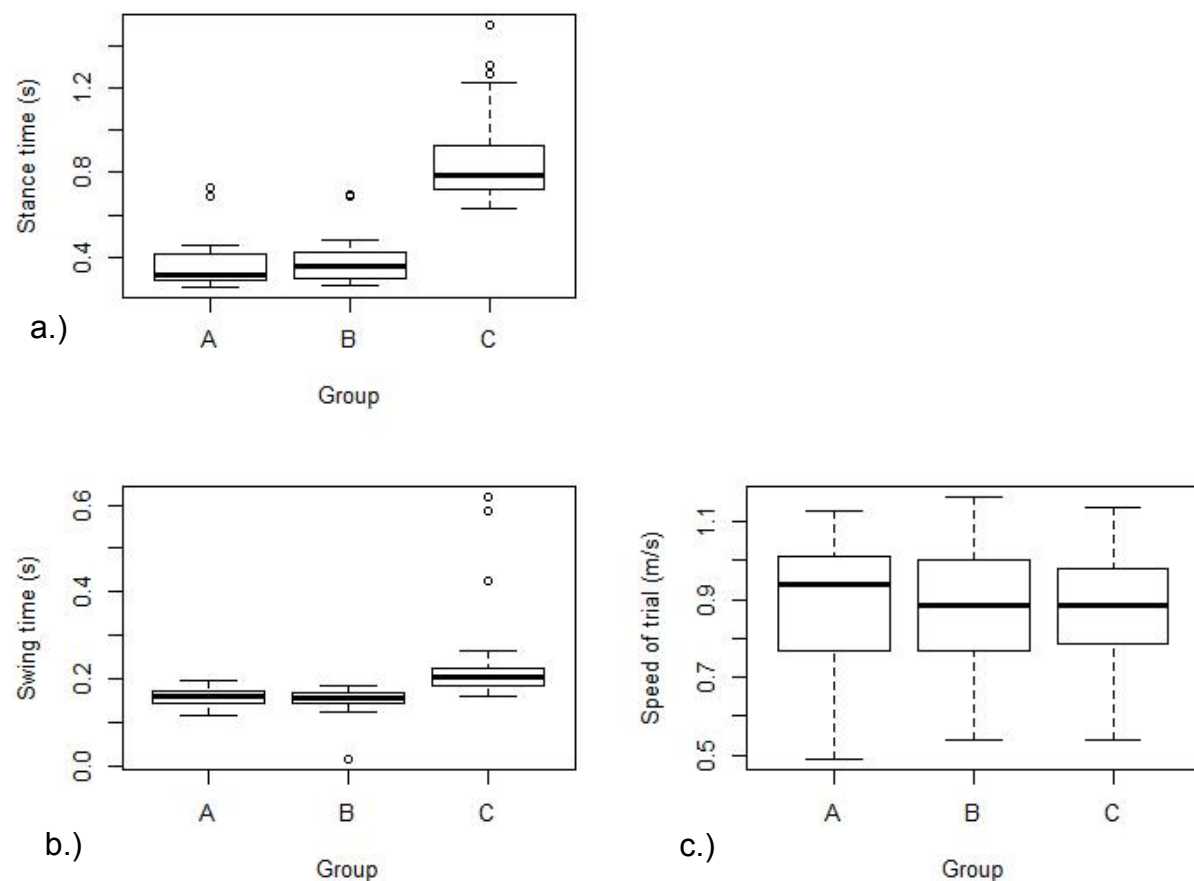
issues with the sensor units. The landing kinematic analysis was performed on the same trials included in the hopping kinematics, however in the case group one other male trial was excluded, but another female trial included (rendering the same number for both kinematic analyses in this group) and one further male trial had to be excluded from the rural control group (refer to Table 4.3 for a summary of the exclusions).

**Table 4.3 Summary of excluded trials**

	<b>Cases</b>	<b>Rural controls</b>	<b>Urban controls</b>
<b>Failed trials</b>	6	0	0
<b>Data file corruptions for all parameters</b>	1	2	0
<b>Data file corruptions for spatiotemporal parameters</b>	0	0	1
<b>Technical problems with inertial sensor units</b>	10	8	3
<b>Participant shuffled on the pressure mat</b>	6	6	6

## 4.5 Spatiotemporal parameters

There were no differences found between left and right legs, thus the sides were combined. Twenty-one case group trials, 26 rural control trials and 53 urban control trials were included for analysis of the spatiotemporal parameters. The box plots in Figure 4.2 (a-c) reflect the distribution of spatiotemporal parameters and the median and range values for all spatiotemporal parameters can be found in Table 4.4.



**Figure 4.2 (a-c) Distribution box plots of the spatiotemporal parameters**

A: case group; B: rural control group; C: urban control group

#### **4.5.1 Stance time**

As a group, urban controls had statistically significant longer stance times compared to both the case group, ( $p < 0.001$ ; Chi-square=70.41;  $U=20$ ;  $Z=-6.43$ ) and the rural control group ( $p < 0.001$ ; Chi-square=70.41;  $U=11$ ;  $Z=-7.01$ ). There were no significant differences between case and rural control groups ( $p=0.56$ ).

#### **4.5.2 Swing time**

The urban control group had statistically significant longer swing times than the case group ( $p < 0.001$ ; Chi-square=60.78;  $U=77.5$ ;  $Z=-5.74$ ) and the rural control group ( $p < 0.001$ ; Chi-square=60.78;  $U=42.5$ ;  $Z=-6.75$ ). No significant differences were found between the case and rural control groups ( $p=0.48$ ).

#### **4.5.3 Speed of trial**

No significant difference was found between the three groups for the speed of the trials ( $p=0.66$ ), however the case group displayed a faster median speed ( $0.94 \text{ m.s}^{-1}$ ) compared to the other groups ( $0.89 \text{ m.s}^{-1}$ ). The females in both the case and rural control groups displayed faster median speeds compared to the males within each group.



**Table 4.4 The median (range) values of spatiotemporal parameters for the movement phase of SLH**

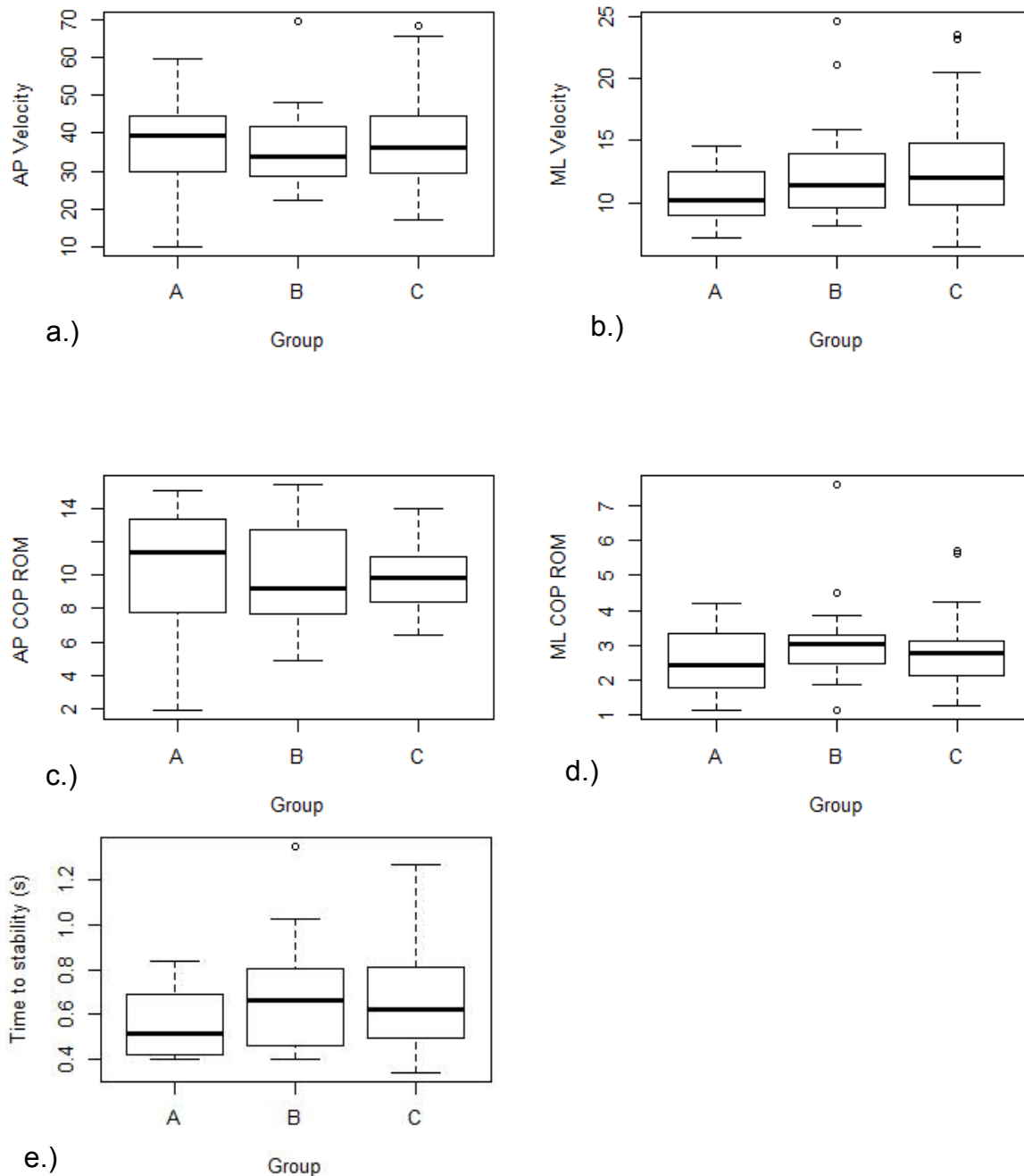
	<b>Cases</b>			<b>Rural controls</b>			<b>Urban controls</b>		
	<b>Group</b>	<b>Males</b>	<b>Females</b>	<b>Group</b>	<b>Males</b>	<b>Females</b>	<b>Group</b>	<b>Males</b>	<b>Females</b>
	<b>n = 21</b>	<b>n = 13</b>	<b>n = 8</b>	<b>n = 26</b>	<b>n = 15</b>	<b>n = 11</b>	<b>n = 53</b>	<b>n = 23</b>	<b>n = 30</b>
<b>Stance time (s)</b>	0.32 (0.26-0.73)	0.4 (0.28-0.73)	0.3 (0.26-0.33)	0.36 (0.26-0.69)	0.4 (0.26-0.69)	0.32 (0.26-0.4)	0.79* (0.63-1.5)	0.79 (0.66-1.1)	0.78 (0.63-1.5)
<b>Swing time (s)</b>	0.16 (0.12-0.2)	0.16 (0.12-0.2)	0.16 (0.12-0.18)	0.15 (0.01-0.18)	0.15 (0.13-0.18)	0.15 (0.01-0.18)	0.2* (0.16-0.62)	0.21 (0.16-0.62)	0.19 (0.16-0.59)
<b>Speed of trial (m.s<sup>-1</sup>)</b>	0.94 (0.49-1.13)	0.81 (0.49-1.13)	0.98 (0.89-1.13)	0.89 (0.54-1.16)	0.83 (0.54-1.16)	0.96 (0.81-1.02)	0.89 (0.54-1.14)	0.89 (0.66-1.05)	0.89 (0.54-1.14)

n: number of trials (left and right side combined); s: seconds; m: metres

\* statistically significant difference (p&lt;0.05)

#### 4.6 Centre of pressure and time to stability

No differences were found between the left and right legs, therefore the sides were combined for analysis. Fifteen case group trials, 20 rural control trials and 48 urban control trials were included for analysis of the COP and TTS parameters. Figure 4.3 (a-e) shows the distribution of COP parameters and TTS.



**Figure 4.3 (a-e) Distribution box plots of the COP parameters and TTS**

A: case group; B: rural control group; C: urban control group

Table 4.5 shows the median and range values for the COP parameters and TTS. No statistically significant differences were found between the three groups for COP parameters ( $AP_{vel}$ :  $p=0.78$ ;  $AP_{ROM}$ :  $p=0.66$ ;  $ML_{vel}$ :  $p=0.23$ ;  $ML_{ROM}$ :  $p=0.18$ ). However, the case group displayed higher median values for  $AP_{vel}$  ( $39.38\text{cm}\cdot\text{s}^{-1}$ ) and  $AP_{ROM}$  ( $11.37\text{cm}$ ) compared to rural controls ( $AP_{vel}$ :  $33.62\text{ cm}\cdot\text{s}^{-1}$ ;  $AP_{ROM}$ :  $9.19\text{cm}$ ) and urban controls ( $AP_{vel}$ :  $36.14\text{ cm}\cdot\text{s}^{-1}$ ;  $AP_{ROM}$ :  $9.81\text{cm}$ ). The females across the groups had higher median  $AP_{vel}$  and  $AP_{ROM}$  values compared to males. Negligible median value differences were found for ML parameters between the groups or per gender. The case group reached stability quicker than both the rural and urban control groups, as they showed lower values of TTS per group, however this finding was not statistically significant ( $p=0.22$ ).

**Table 4.5 The median (range) values of COP parameters and TTS for the landing phase of SLH**

	Cases			Rural controls			Urban controls		
	Group n = 15	Males n = 8	Females n = 7	Group n = 20	Males n = 12	Females n = 8	Group n = 48	Males n = 22	Females n = 26
<b>AP<sub>vel</sub></b> <b>(cm.s<sup>-1</sup>)</b>	39.38 (10.13-59.66)	31.7 (10.13-51.89)	43.35 (21.75-59.66)	33.62 (22.46-69.52)	32.18 (22.46-47.91)	35.78 (28.49-69.52)	36.14 (17.26-68.26)	33.51 (23.1-68.26)	37.51 (17.26-55.23)
<b>ML<sub>vel</sub></b> <b>(cm.s<sup>-1</sup>)</b>	10.22 (7.22-14.57)	11.76 (8.12-14.57)	9.14 (7.22-13.18)	11.39 (8.16-24.61)	10.9 (8.16-24.61)	12.06 (9.03-21.06)	12.01 (6.47-23.52)	12.43 (6.93-23.52)	11.87 (6.47-20.51)
<b>AP<sub>ROM</sub></b> <b>(cm)</b>	11.37 (1.89-15.06)	9.11 (1.89-14.51)	12.35 (7.16-15.06)	9.19 (4.86-15.39)	10.17 (6.2-15.39)	8.27 (4.86-13.95)	9.81 (6.4-13.98)	9.49 (6.66-13.16)	10.01 (6.4-13.98)
<b>ML<sub>ROM</sub></b> <b>(cm)</b>	2.42 (1.14-4.2)	2.55 (1.14-4.2)	2.14 (1.31-3.87)	3.05 (1.13-7.58)	3.05 (1.86-7.58)	3.05 (1.13-4.5)	2.76 (1.27-5.72)	2.8 (1.73-4.24)	2.61 (1.27-5.72)
<b>TTS</b> <b>(s)</b>	0.52 (0.4-0.84)	0.53 (0.4-0.84)	0.52 (0.4-0.83)	0.66 (0.4-1.35)	0.69 (0.43-1.35)	0.58 (0.4-0.77)	0.62 (0.34-1.27)	0.6 (0.34-1.27)	0.63 (0.41-0.99)

n: number of trials (left and right side combined); COP: centre of pressure; AP: anteroposterior; ML: mediolateral; vel: velocity; ROM: range of movement; TTS: time to stability; cm: centimetres; s: seconds

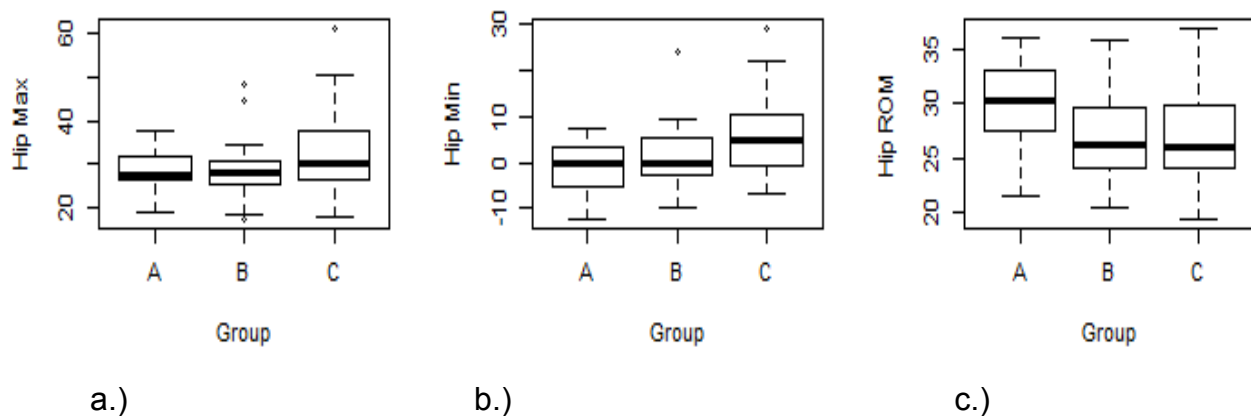
## 4.7 Kinematics

There were no differences between left and right legs for kinematics of the hip, knee or ankle, and thus the sides were combined for analysis. Eleven case group trials, 19 rural control group trials and 51 urban control group trials were included for the analysis of the hopping kinematic parameters.

### 4.7.1 Hopping kinematics

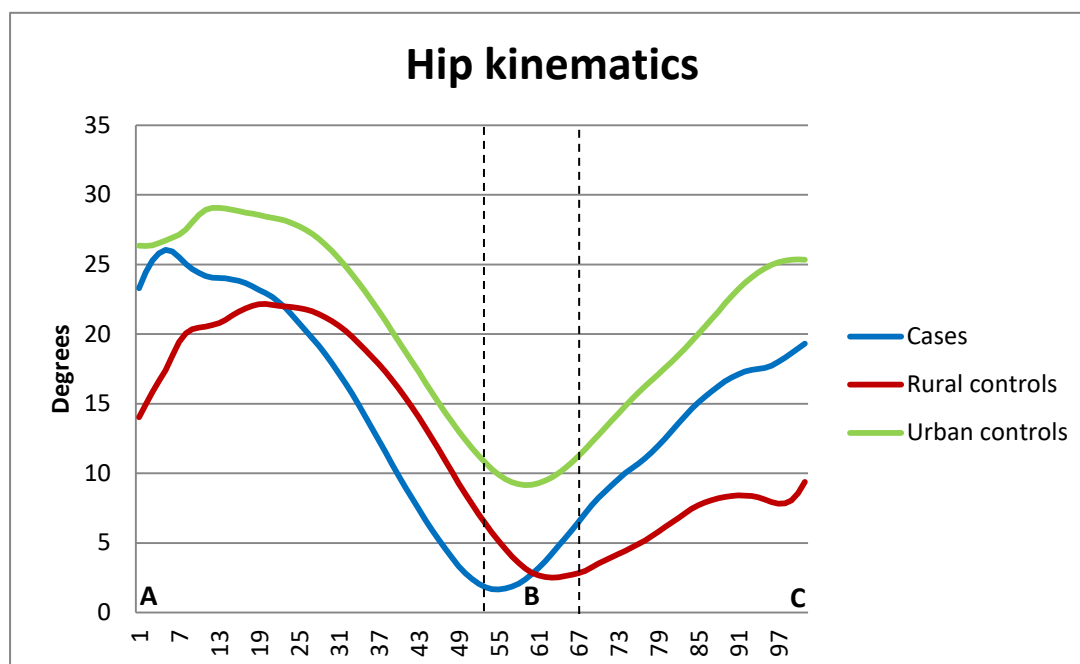
#### 4.7.1.1 Hip

Figure 4.4 (a-c) shows the distribution of hip kinematic parameters. Figure 4.5 is the graphical representation of the kinematic patterns derived from the median values of all four hops for the hip joint captured throughout the hopping cycle per group. Positive angles reflect hip flexion and negative angles indicate hip extension.



**Figure 4.4 (a-c) Distribution box plots of the hip kinematic parameters**

A: case group; B: rural control group; C: urban control group; max: maximum; min: minimum; ROM: range of motion



**Figure 4.5 Hip kinematic pattern from foot contact in one block (A) to consecutive foot contact (C)**

A: foot contact; A to B: stance phase; B: foot off; B to C: swing phase; C: initial foot contact (IFC)

Table 4.6 shows the median and range values for the kinematic parameters of the hip joint. The urban control group adopted a more flexed position at the hip compared to the case group (statistical significance of  $p=0.02$ ; Chi-square=7.43;  $U=151$ ;  $Z=-2.39$ ), indicated by higher minimum values (highlighted in Figure 4.5 and Table 4.6). While not significantly different, the urban control group adopted a more flexed position at the hip compared to the rural control group as well ( $p=0.08$ ). Urban control females hopped with statistically significant more hip flexion (indicated by higher minimum values) compared to the rural control group females ( $p=0.01$ ; Chi-square=6.87;  $U=40$ ;  $Z=-2.46$ ) and urban males displayed statistically significant more hip flexion during hopping than the case group males ( $p=0.02$ ; Chi-square=6.26;  $U=25$ ;  $Z=-2.3$ ). Overall median values indicate that males remained more flexed at the hip throughout the hops compared to females across the three groups, with urban males reflecting the biggest hip flexion angles (see Table 4.6).

**Table 4.6 The median (range) of maximum and minimum values and ROM for sagittal plane kinematics of the hip joint**

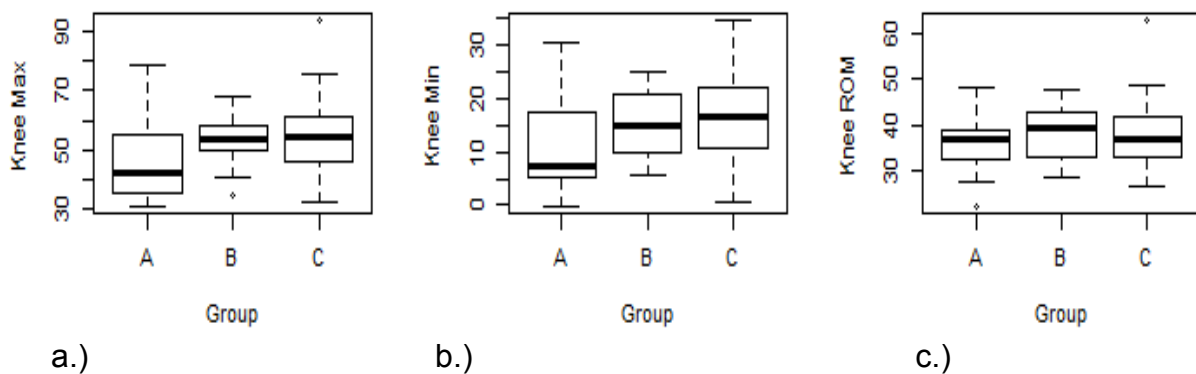
	Cases			Rural controls			Urban controls		
	Group n = 11	Males n = 6	Females n = 5	Group n = 19	Males n = 12	Females n = 7	Group n = 51	Males n = 22	Females n = 29
<b>Maximum°</b>									
Hop 1	28.86 (19.39-39.91)	27.5 (24.01-38.18)	30.11 (19.39-39.91)	27.45 (13.64-52.71)	30.35 (13.64-52.71)	25.49 (17.34-28.92)	33.74 (17.49-64.78)	35.66 (23.43-64.78)	30.33 (17.49-54.71)
Hop 2	26.48 (18.87-34.95)	26.36 (18.87-34.95)	26.48 (20.84-32.66)	27.26 (16.4-49.9)	31.62 (17.17-49.90)	26.46 (16.40-28.54)	30.96 (18.04-60.95)	32.95 (19.60-60.95)	29.86 (18.04-52.50)
Hop 3	27.48 (17.88-37.11)	29.05 (19.03-37.11)	27.48 (17.88-36.27)	27.66 (11.14-46.52)	30.77 (11.14-46.52)	26.86 (17.29-28.56)	30.35 (13.61-65.06)	32.89 (14.77-65.06)	27.63 (13.61-44.11)
Hop 4	28.06 (19.11-41.32)	30.15 (23.7-38.09)	25.49 (19.11-41.32)	29.25 (16.75-47.34)	32.34 (16.75-47.34)	25.19 (18.51-30.06)	29.07 (15.78-53.74)	32.34 (15.78-53.74)	27.63 (16.46-50.63)
<b>Median of four hops°</b>	27.77	28.27	26.98	27.55	31.19	25.97	30.65	32.92	28.75
<b>Minimum°</b>									
Hop 1	-2.51 (-11.02-8.68)	-3.73 (-9.49-3.93)	-0.76 (-11.02-8.68)	2.09 (-9.37-26.88)	5.82 (-4.23-26.88)	-1.63 (-9.37-3.44)	5.03 (-11.84-29.03)	8.34 (-1.38-29.03)	2.71 (-11.84-23.11)
Hop 2	-3.20 (-12.55-6.95)	-2.19 (-12.55-6.95)	-3.20 (-11.55-3.89)	0.51 (-10.83-22.02)	3.12 (-5.15-22.02)	-3.96 (-10.83 - -0.43)	3.13 (-8.22-34.43)	6.18 (-5.31-34.43)	1.48 (-8.22-21.85)
Hop 3	1.33 (-14.18-11.41)	3.46 (-12.60-11.41)	-5.39 (-14.18-2.72)	0.15 (-9.66-22.95)	3.80 (-6.92-22.95)	-3.55 (-9.66-1.74)	4.42 (-10.62-27.2)	8.42 (-7.95-27.20)	1.75 (-10.62-15.42)
Hop 4	1.58 (-14.69-13.79)	3.36 (-14.69-8.86)	-6.69 (-13.00-13.79)	0.27 (-10.16-24.68)	5.76 (-7.74-24.68)	-3.08 (-10.16-0.48)	5.61 (-7.98 - 27)	9.32 (-7.98-27)	1.31 (-7.58-22.64)
<b>Median of four hops°</b>	-0.59*	0.59***	-4.3	0.39	4.78	-3.31**	4.72*	8.38***	1.62**
<b>ROM° (max - min)</b>	28.36	27.68	31.28	27.16	26.41	29.28	25.93	24.54	27.13

n: number of trials; ROM: range of motion; max: maximum; min: minimum

\*, \*\*, \*\*\* statistically significant difference between groups (p&lt;0.05)

#### 4.7.1.2 Knee

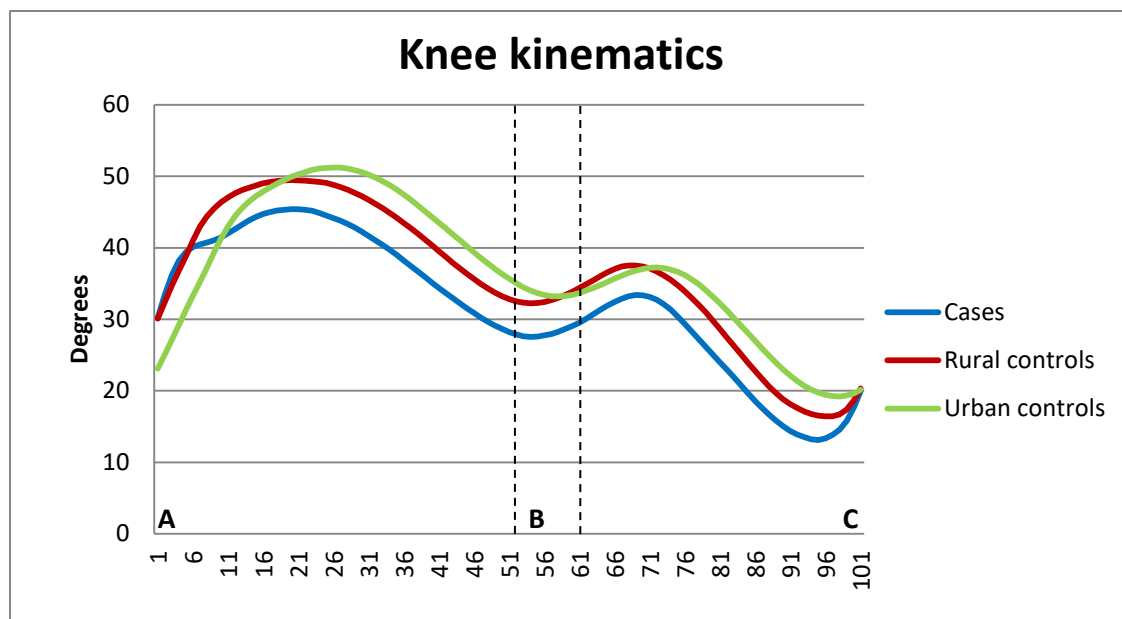
Figure 4.6 (a-c) displays the distribution of knee kinematic parameters. Figure 4.7 is the graphical representation of the kinematic patterns derived from the median values of all four hops for the knee joint captured throughout the hopping cycle per group. Positive angles reflect flexion of the knee and negative angles indicate extension of the knee.



**Figure 4.6 (a-c) Distribution box plots of the knee kinematic parameters**

A: case group; B: rural control group; C: urban control group; max: maximum; min: minimum; ROM: range of motion





**Figure 4.7 Knee kinematic pattern from foot contact in one block (A) to consecutive foot contact (C)**

A: foot contact; A to B: stance phase; B: foot off; B to C: swing phase; C: initial foot contact (IFC)

Table 4.7 shows the median and range values for the kinematic parameters of the knee joint. Rural and urban controls adopted a more flexed position at the knee (indicated by higher median values for minimum knee angles) and travelled through more knee ROM compared to the case group (highlighted in Table 4.7), although these differences were not statistically significant (knee min:  $p=0.16$ ; knee ROM:  $p=0.64$ ). Urban and rural control group females hopped with statistically significant more knee flexion compared to case group females (Chi-square=7.28; rural controls and case group:  $p=0.01$ ;  $U=2$ ;  $Z=-2.52$ ; urban controls and case group:  $p=0.03$ ;  $U=28$ ;  $Z=-2.16$ ). There were no significant differences between the males across the three groups (knee min:  $p=0.33$ ; knee ROM:  $p=0.73$ ). Overall, the case group moved through less ROM and hopped in an increasingly extended position at the knee with each hop, thereby becoming more extended at the knee as they approached the pressure mat to land.

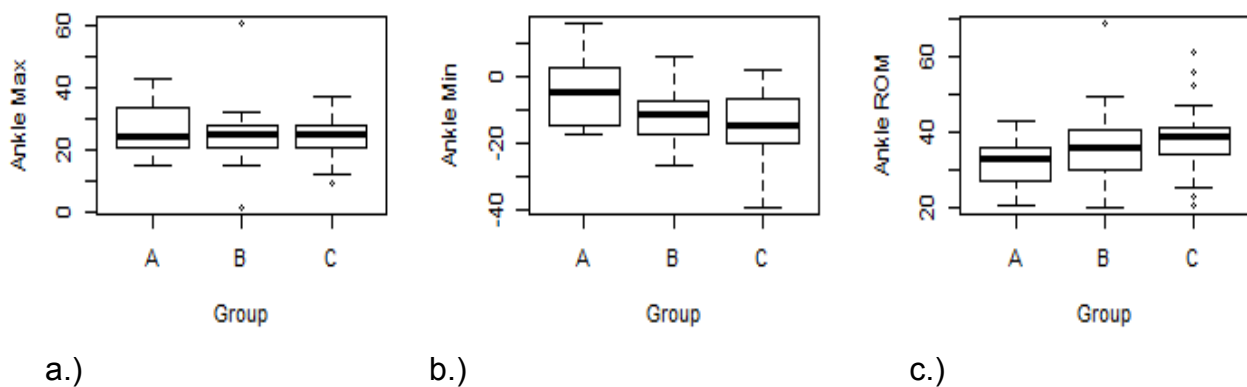
**Table 4.7 The median (range) of maximum and minimum values and ROM for sagittal plane kinematics of the knee joint**

		Cases			Rural controls			Urban controls		
		Group	Males	Females	Group	Males	Females	Group	Males	Females
		n = 11	n = 6	n = 5	n =19	n = 12	n = 7	n = 51	n = 22	n = 29
Maximum°	Hop 1	46.03	48.64	46.03	51.56	51.20	53	54.33	56.97	53.38
		(31.85-77.13)	(31.85-77.13)	(32.07-55.52)	(30.27-67.05)	(30.27-62.99)	(48.19-67.05)	(31.1-87.38)	(37.29-87.38)	(31.10-71.63)
	Hop 2	43.62	48.86	43.62	52.72	50.85	56.86	52.45	54.43	52.02
		(28.35-83.34)	(28.35-83.34)	(31.85-55.50)	(34.44-68.37)	(34.44-62.49)	(48-68.37)	(29.25-92.32)	(32.73-92.32)	(29.25-75.25)
	Hop 3	40.68	46.47	40.68	53.34	53.19	55.97	54.95	55.30	54.95
		(31.38-76.32)	(31.38-76.32)	(31.86-50.36)	(38.09-70.09)	(38.09-70.09)	(49.60-68.71)	(31.8-98.27)	(37.55-98.27)	(31.80-71.03)
	Hop 4	39.96	50.68	38.18	54.63	54.81	53.48	53.63	54.04	52.88
		(33.1-76.74)	(33.10-76.74)	(34.53-56.47)	(35.48-67.03)	(35.48-65.03)	(49.87-67.03)	(30.88-94.52)	(36.52-94.52)	(30.88-72.81)
Median of four hops°		42.15	48.75	42.15	53.03	52.19	54.72	53.98	54.85	53.13
Minimum°	Hop 1	10.77	15.46	10.77	17.42	10.23	25.87	15.39	15.49	15.36
		(0.29-31.93)	(1.80-31.93)	(0.29-21.98)	(2.65-28.22)	(2.65-23.47)	(17.42-28.22)	(0.84-40.44)	(1.30-40.44)	(0.84-30.63)
	Hop 2	8.48	15.29	7.64	15.94	13.97	22.61	16.36	17.50	15.78
		(1.36-32.37)	(3.47-32.37)	(1.36-14.71)	(4.22-27.56)	(4.22-24.14)	(15.84-27.56)	(1.17-33.40)	(1.36-33.40)	(1.17-31.04)
	Hop 3	7.9	14.95	5.71	14.79	12.27	19.88	16.47	14.88	17.46
		(0.65-32.49)	(1.82-32.49)	(0.65-20.29)	(-0.1-26.74)	(-0.1-22.82)	(10.43-26.74)	(-2.35-32.84)	(-2.35-32.84)	(0.70-29.33)
	Hop 4	5.07	9.73	3.97	11.23	9.18	16.36	16.01	15.64	16.84
		(-3.02-25.44)	(3.42-25.44)	(-3.02-12.65)	(0.26-28.73)	(0.26-28.73)	(10.39-22.25)	(-1.15-35.7)	(-1.15-35.70)	(1.43-27.20)
Median of four hops°		8.19	15.12	6.67	15.37	11.25	21.25*	16.19	15.57	16.31*
ROM° (max - min)		33.96	33.63	35.48	37.66	40.94	33.47	37.79	39.28	36.82

n: number of trials; ROM: range of motion; \*statistically significant difference (p&lt;0.05)

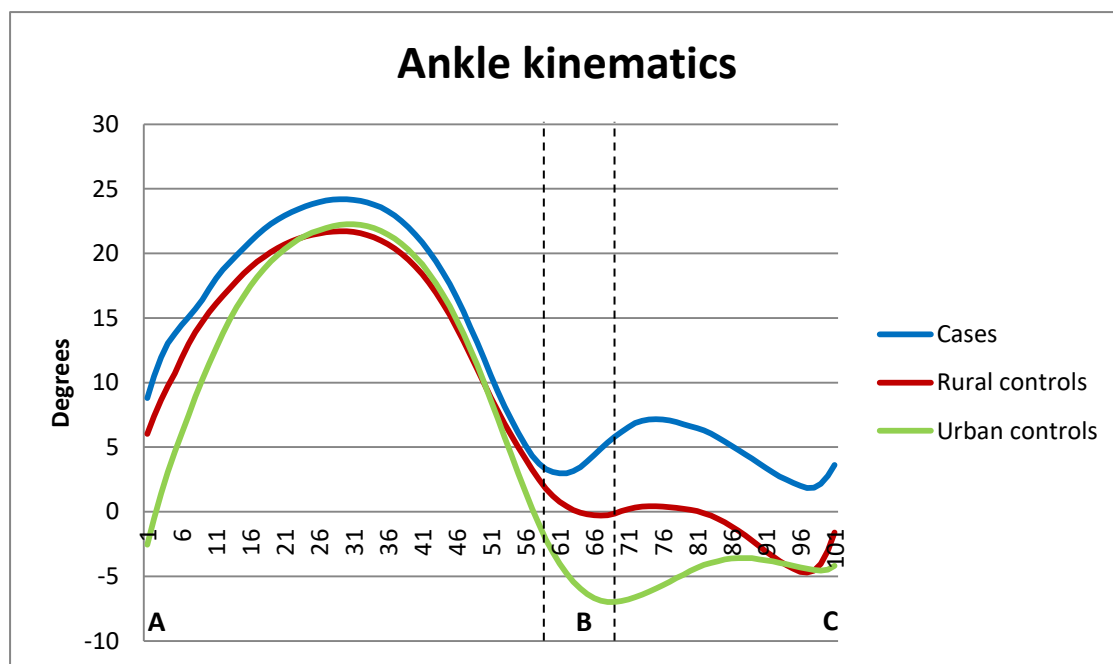
#### 4.7.1.3 Ankle

Figure 4.8 (a-c) shows the distribution of ankle kinematic parameters. Figure 4.9 is the graphical representation of the kinematic patterns derived from the median values of all four hops for the ankle joint captured throughout the hopping cycle per group and Table 4.8 shows the median and range values for the kinematic parameters of the ankle joint. Positive angles reflect dorsiflexion of the ankle, while negative angles indicate plantarflexion of the ankle.



**Figure 4.8 (a-c) Distribution box plots of the ankle kinematic parameters**

A: case group; B: rural control group; C: urban control group; max: maximum; min: minimum; ROM: range of motion



**Figure 4.9 Ankle kinematic pattern from foot contact in one block (A) to consecutive foot contact (C)**

A: foot contact; A to B: stance phase; B: foot off; B to C: swing phase; C: initial foot contact (IFC)

The urban control group hopped with increased plantarflexion (see Figure 4.9) and went through the biggest range of movement at the ankle during hopping compared to the other two groups (see Table 4.8), although these differences were not statistically significant (ankle min:  $p=0.07$ ; ankle ROM:  $p=0.07$ ). Rural controls displayed similar movement at the ankle to the urban controls, however with less median plantarflexion and ROM. The case group, and particularly the males, did not move into plantarflexion as much and rather remained in a more neutral to dorsiflexed position throughout the hopping cycle (Table 4.8).

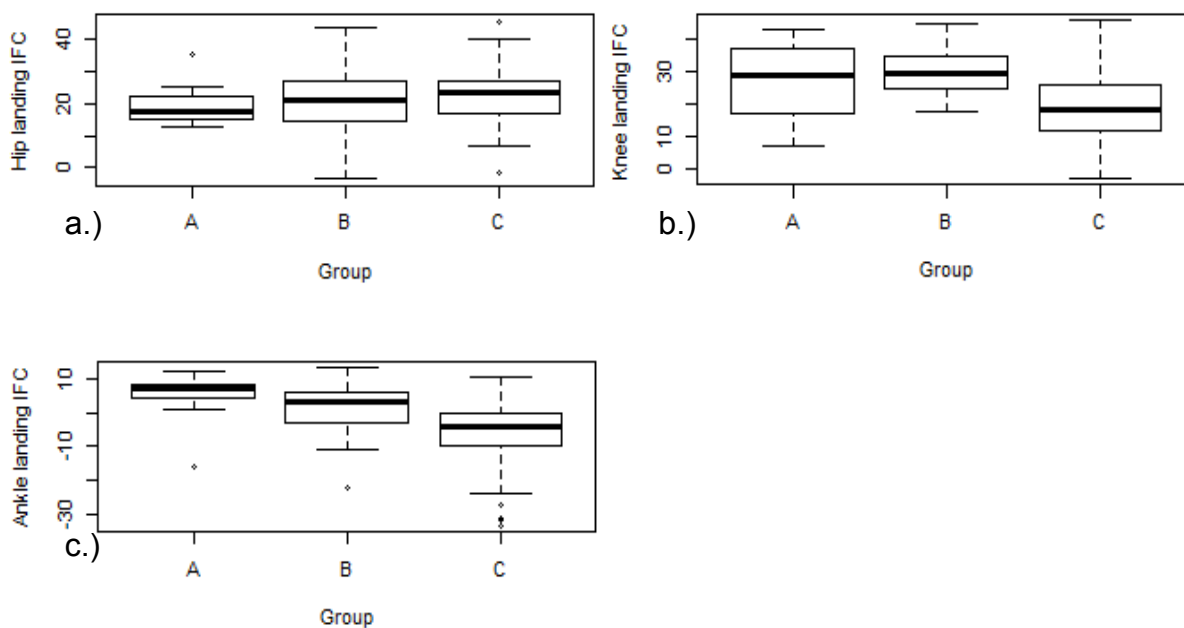
**Table 4.8 The median (range) of maximum and minimum values and ROM for sagittal plane kinematics of the ankle joint**

		Cases			Rural controls			Urban controls		
		Group	Males	Females	Group	Males	Females	Group	Males	Females
		n = 11	n = 6	n = 5	n =19	n = 12	n = 7	n = 51	n = 22	n = 29
Maximum°	Hop 1	24.99	34.52	20.30	23.41	22.86	24.54	24.61	24.21	26.84
		(15.61-41.53)	(18.13-41.53)	(15.61-25.82)	(0.8-58.81)	(15.08-58.87)	(16.42-33.38)	(6.81-36.98)	(6.81-34.82)	(12.72-36.98)
	Hop 2	25.02	35.19	21.24	26.08	24.86	27.09	24.04	24.23	23.72
		(15.27-45.55)	(16.89-45.55)	(15.27-25.02)	(3.79-59.31)	(14.37-59.31)	(17.01-31.98)	(4.24-38.21)	(4.24-38.21)	(6.18-33.47)
	Hop 3	22.58	35.17	21.73	25.13	25.13	25.30	24.2	24.03	24.34
		(16.85-43.24)	(16.85-43.24)	(18.56-22.58)	(1-72.09)	(11.23-72.09)	(21.80-31.82)	(6.59-40.56)	(6.59-40.56)	(9.63-36.15)
	Hop 4	23.06	29.26	22.59	24.44	23.02	29.24	25	23.89	25.33
		(11.65-43.81)	(19.42-43.81)	(11.65-23.06)	(1.77-51.04)	(14.16-51.04)	(20.08-33.83)	(11.79-35.89)	(11.79-35.89)	(12.52-33.66)
Median of four hops°		24.02	34.85	21.49	24.78	23.94	26.19	24.4	24.12	24.83
Minimum°	Hop 1	-5	1.07	-13.19	-10.28	-14.31	-4.70	-14.2	-14.21	-13.23
		(-16.01-20.82)	(-16.01-4.75)	(-15.50-4.48)	(-27.05-7.17)	(-27.05-7.17)	(-19.79-1.53)	(-40.68-5.61)	(-38.45-5.61)	(-40.68-2.80)
	Hop 2	-5.45	-1.61	-8.45	-12.75	-12.94	-5.93	-12.46	-12.69	-12.19
		(-18.68-17.05)	(-18.68-7.05)	(-14.90-3.05)	(-27.95-9.82)	(-27.95-9.82)	(-23.83 - -1.50)	(-43.69-5.75)	(-36.22-1.83)	(-43.69-5.75)
	Hop 3	-6.17	-1.63	-11.58	-10.06	-13.63	-8.62	-13.2	-12.46	-15.19
		(-24.07-16.13)	(-24.07-3.94)	(-13.69-4.19)	(-28.9-6.11)	(-28.90-6.11)	(-28.30-2.15)	(-47.23-6.72)	(-41.33-6)	(-47.23-6.72)
	Hop 4	-2.75	-1.81	-9.01	-10.19	-15.66	-9.40	-13.29	-13.53	-12.59
		(-23.94-8.58)	(-23.94-0.18)	(-17.65 - -0.08)	(-31.6-3.84)	(-31.60-3.84)	(-30.75 - -4.04)	(-44.8-9.14)	(-33.78-3.24)	(-44.80-9.14)
Median of four hops°		-5.22	-1.62	-10.3	-10.24	-13.97	-7.27	-13.24	-13.11	-12.91
ROM° (max - min)		29.24	36.47	31.79	35.02	37.91	33.46	37.64	37.23	37.74

n: number of trials; ROM: range of motion; max: maximum, min: minimum

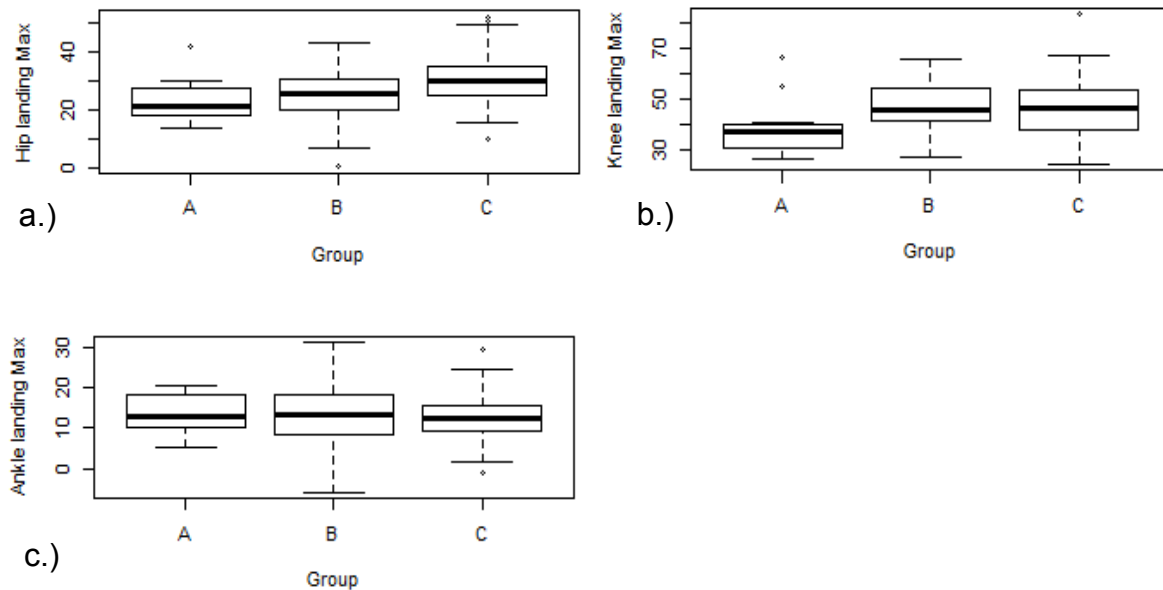
#### 4.7.2 Landing Kinematics

Eleven case group trials, 18 rural control group trials and 51 urban control group trials were included in the landing kinematic analysis. There were no differences between left and right sides, so they were combined. Figure 4.10 (a-c) shows the distribution of hip, knee and ankle IFC angles upon landing on the pressure mat and Figure 4.11 (a-c) shows the distribution of hip, knee and ankle maximum angles during landing. Table 4.9 shows the median (range) values for landing kinematics of the hip, knee and ankle joints during the last landing of the trial onto the pressure mat.



**Figure 4.10 (a-c) Distribution box plots of the hip, knee and ankle IFC landing kinematics**

A: case group; B: rural control group; C: urban control group; max: maximum; min: minimum; ROM: range of motion



**Figure 4.11 (a-c) Distribution box plots of the hip, knee and ankle maximum landing kinematics**

A: case group; B: rural control group; C: urban control group; max: maximum; min: minimum; ROM: range of motion

Rural and urban control groups landed in a more flexed position of the hip compared to the case group as they displayed bigger median angles at the hip at IFC (see Table 4.9), although this was not statistically significant ( $p=0.23$ ). The urban control group moved into statistically significant greater hip flexion (maximum hip angle) during landing on the pressure mat compared to the case group ( $p=0.02$ ; Chi-square=9.04;  $U=149$ ;  $Z=-2.42$ ) and the rural control group ( $p=0.03$ ;  $U=296$ ;  $Z=-2.23$ ). Therefore, the case group landed with a more extended hip, and maintained a more upright position of the body when landing.

The case and rural control groups showed statistically significant greater knee flexion angles at IFC than the urban control group indicating a more flexed position of the knee upon landing (Chi-square=16.98; case and urban control groups:  $p=0.04$ ;  $U=169$ ;  $Z=-2.01$ ; rural and urban control groups:  $p<0.001$ ;  $U=167$ ;  $Z=-3.99$ ) (see

Table 4.9). Both the rural and urban control groups travelled into a more flexed position of the knee (median maximum knee angles) during landing compared to the case group, although this difference was not statistically significant ( $p=0.09$ ).

For the ankle (Table 4.9), the urban control group landed in a statistically significant more plantarflexed position at IFC compared to the case group ( $p<0.001$ ; Chi-square=20.34;  $U=69$ ;  $Z=-3.9$ ) and the rural control group ( $p=0.003$ ;  $U=239$ ;  $Z=-3.01$ ). Therefore, the case and rural control groups both landed in a more neutral to dorsiflexed position, more so for the cases.



**Table 4.9 The median (range) values of the hip, knee and ankle landing kinematics during the last land onto the pressure mat**

	Cases			Rural controls			Urban controls		
	Group n = 11	Males n = 7	Females n = 4	Group n = 18	Males n = 11	Females n = 7	Group n = 51	Males n = 22	Females n = 29
<b>Hip IFC°</b>	17.40 (12.74- 35.07)	15.10 (12.74- 24.95)	18.84 (17.33- 35.07)	20.89 (-3.39- 43.16)	23.13 (-3.39- 43.16)	15.74 (8.69- 26.97)	22.74 (-1.22- 45.35)	23.84 (4.24- 45.35)	22.20 (-1.22- 32.14)
<b>Hip Maximum°</b>	21.43 (13.7- 41.87)	22.99 (13.70- 29.78)	19.98 (17.33- 41.87)	25.76 (0.71- 43.16)	27.74 (0.71- 43.16)	21.08 (10.12- 28.71)	30.04* (7.31- 51.89)	33.02 (7.31- 51.89)	26.46 (15.85- 49.24)
<b>Knee IFC°</b>	28.82* (7.27- 43.13)	35.82 (7.27- 43.13)	27.39 (15.72- 33.61)	29.42* (18.11- 44.72)	28.32 (18.11- 38.03)	32.26 (18.36- 44.72)	18.96 (-2.60- 45.78)	20.82 (3.42- 45.78)	17.65 (-2.60- 34.06)
<b>Knee Maximum°</b>	37.15 (26.74- 66.29)	40.17 (26.74- 66.29)	33.55 (29.07- 37.15)	46.09 (27.21- 65.54)	45.47 (27.21- 65.54)	50.17 (43.74- 58.82)	46.74 (24.53- 83.07)	46.51 (24.53- 83.07)	48.63 (24.66- 64.41)
<b>Ankle IFC°</b>	7.36 (-16.09- 12.34)	8.13 (4.43- 8.14)	2.57 (-16.09- 10.49)	3.56 (-22.15- 13.57)	1.75 (-22.15- 13.57)	4.55 (-5.50- 11.46)	-3.71* (-33.45- 10.98)	-1.78 (-31.91- 10.98)	-4.73 (-33.45- 6.64)
<b>Ankle Maximum°</b>	12.88 (5.14- 20.57)	18.09 (9.63- 18.09)	10.42 (5.14- 10.42)	13.31 (-5.87- 31.42)	11.15 (-5.87- 31.42)	17.45 (6.80- 21.64)	13.28 (-1.23- 29.49)	11.74 (2.95- 29.49)	13.61 (-1.23- 24.91)

n: number of trials; IFC: initial foot contact

The mean values for all postural stability and kinematics parameters can be found in Addendum M.

## Chapter 5

### DISCUSSION

The aim of this study was to describe the movement patterns and DPS of nine-year-old children (with and without FASD) during a consecutive SLH task to land and stabilise on a pressure mat. To our knowledge this is the first study of this kind to be conducted in children in South Africa and internationally, and although motor function and postural stability studies have been conducted in children with and without FASD around the world (Roebuck et al, 1998; Jirikowic et al, 2013; Davies et al, 2011; Kooistra et al, 2009), this is the first to incorporate a dynamic, gross motor functioning task i.e. consecutive SLH.

#### 5.1 Demographics

The case group were shorter and weighed less compared to the control groups. This is expected since growth deficiency is a key feature of FASD (O'Leary, 2004). Alcohol is a teratogen that can directly disrupt organ and CNS development, skeletal growth and nutrition of the foetus (Thomas et al, 2010). Growth deficiency is seen in children with FASD prenatally as low birthweight for gestational age, and postnatally as lack of growth in spite of adequate nutrition and a low weight to height ratio (O'Leary, 2004). Confirmed prenatal or postnatal height, weight, or head circumference of below the 10<sup>th</sup> percentile is considered growth deficiency in the diagnosis of FASD (Bertrand et al, 2005; Hoyme et al, 2016). Other features of FASD include characteristic facial features, such as epicanthal folds, thin upper lip and flattened philtrum (O'Leary, 2004), and CNS impairment such as developmental delay and impairments in motor performance (O'Leary, 2004).

## 5.2 Single leg hopping task

Motor impairments relating to movement coordination, timing, balance and dynamic postural stability are reported in children with FASD (Lucas et al, 2014; Bay & Kesmodel, 2011) and therefore a consecutive hopping task was examined in this study to describe these motor functions. Of the 14 children in the case group, four children were unable to complete the task successfully according to the criteria and verbal instructions provided, as described in section 3.14.4. All children in both control groups could successfully complete the task for both left and right legs. This may indicate that the case group experienced the most difficulty executing the task.

This is in line with previous motor function studies that found children with FASD struggle with tasks that require more complex motor skills such as maintaining balance, movement timing and coordination and postural stability (Kooistra et al, 2009; Lucas et al, 2014). Consecutive SLH to land and stabilise on a mat requires sufficient postural stability, sensorimotor control, balance, and motor planning and sequencing. The integration of these body systems have been found to be impaired in children with FASD (Jirikowic et al, 2008; 2013; Roebuck et al, 1998) and due to the fact that this integration occurs at a cerebral level, these impairments have been linked to brain damage caused by PAE (Roebuck et al, 1998).

The consecutive SLH task was chosen in this study as it is one of the dynamic balance tasks included in the MABC assessment used on children aged nine to 10 years old (Henderson & Sugden, 1992). It was therefore assumed that the task would be of appropriate difficulty for the nine-year-old children included in this study. The fact that four children in case group were unable to complete the task

successfully may highlight that this task may be sensitive enough to identify impairments of motor function and possibly DPS in children with FASD, as it was able to identify these children who may need further motor examination. On the other hand however, four out of 14 children is a large portion of the case group and this may indicate that in fact the task was too difficult for the children. Despite it being used in the MABC assessment, it may only be a suitable task for this age group when being rated by an observer on a performance scale (as done in the MABC), rather than being analysed with a motion analysis system which requires more rigorous exclusions to ensure the data is correct.

Upon viewing the failed trials of these four case group children, it appeared that commonly the mistakes occurred closer to the end of the task, at the pressure mat. It may be that the anticipation of landing on the mat and the added instructions of maintaining balance on one leg, with the foot straight, for a certain period of time, made this task more difficult for these children. This could potentially indicate that these children struggled with the planning, sequencing and execution of this task, as displayed by the poor control of spatiotemporal and kinematic parameters during the SLH task. These parameters are examined in DPS and motor function/coordination research, and while clinical assessments (e.g. the MABC) may identify problems relating to these parameters, laboratory type assessments can provide deeper and more specific analysis of movement and motor function.

### 5.3 Spatiotemporal parameters

Spatiotemporal parameters are commonly examined in gait studies to quantitatively describe the events of gait which include stance time, swing time, speed and cadence (Bugane et al, 2012). These parameters identify how the body is accepting weight, supporting body weight on one leg and moving the swing leg forward, therefore reflecting overall task execution (Bugane et al, 2012). In accordance with this, it seems plausible that when investigating a consecutive SLH task, these parameters would be important to examine.

In this study, the urban controls displayed statistically significant longer swing and stance times compared to both case and rural control groups. Video analysis of the SLH task showed that the urban control group hopped higher than the rural groups, had longer contact with the ground between each hop and had longer swing times during the hops. A study by Pittenger et al (2002) investigated in-place single leg and double leg jumping in healthy children aged 10 to 11 years old and they found that there was a longer mean flight time (0.19s) during double leg jumping compared to 0.12s during one leg hopping. This was due to a greater vertical height (observed by the authors but not measured) produced during double leg jumping compared to single leg jumping. This greater vertical height translated into longer flight times (Pittenger et al, 2002) and although the height of the hops were not measured in this study as well, this may explain the longer swing times of the urban control group.

Similar spatiotemporal parameters were reported in a study conducted by Parker et al (1993) in which typically developed children between the ages of three and nine years old performed in-place repetitive bilateral jumping and SLH. Parker et al (1993)

found that the older age groups (eight to nine years) displayed significantly longer time in the air than younger age groups for the SLH task. The eight to nine year old children had a mean “air time” of 0.2s and this is similar to the median swing time value of 0.2s measured in our urban control group. Our rural control and case group swing times (0.15s and 0.16s respectively) are comparable to the mean “air time” of 0.15s found in the group of six to seven year olds in the study by Parker and colleagues (1993) and the mean “flight time” of 0.12s recorded for the 10 to 11 year old children completing the single leg jumping task in the study by Pittenger et al (2002).

Parker et al (1993) explained the finding of significantly longer air times in the eight to nine year old group, as older children displaying better motor coordination and improved ability to integrate perceptual factors such as timing and control of the body over the stabilising leg. They also suggested that the greater propulsion in an upwards direction displayed by the older children showed improved lower limb muscle strength and control compared to the younger age groups (Parker et al, 1993). A study conducted by Tveter et al (2010) examined SLH distance in healthy children aged seven to 12 years and found that thigh muscle strength was a strong predictor of hop distance. Although hop distance and vertical height are not necessarily directly comparable, it is plausible to deduce that if a child hops further due to increased muscle strength, they may also be able to hop higher, as the urban control group did in the current study.

In terms of stance time, the authors in the study by Parker et al (1993) found small differences in mean ground contact times between hops for the different age groups.

The older group (eight to nine year olds) displayed a slightly longer mean ground contact time of 0.28s compared to 0.26s in six to seven year olds. Pittenger et al (2002) found that children performing the single leg jump task anticipated higher peak GRF during a single leg land compared to a double leg land, and therefore spent significantly longer time in contact with the ground (0.56s) between each hop compared to the double leg jumping task (0.2s). The authors suggested this manifestation could be an attempt by the children to decrease the overall peak GRF experienced during a single leg land because the increased contact time with the ground between hops would more effectively dissipate the landing GRF (Pittenger et al, 2002). The values for ground contact time found in the study by Parker et al (1993) are smaller than those found in our study where median stance times of 0.79s, 0.36s and 0.32s were measured for urban controls, rural controls and cases respectively. The mean stance time of 0.56s found in the Pittenger et al (2002) study however, falls between the values measured in our urban and rural groups.

Taking the abovementioned spatiotemporal factors into consideration, the greater the vertical displacement and the longer air time during forward consecutive hopping (seen in the urban control group), the better the ability to dissipate the anterior momentum and control the body's weight over the hopping leg. The longer stance time during hopping, seen in the urban control group, facilitates force dissipation to reduce impact on the body during landing and may assist with balancing on one leg. During landing from a hop, the lower limb musculature must decelerate and control the body's COM as it travels downwards and in an anterior direction to transition the body from a dynamic to a static state safely (Wikstrom et al, 2004). Dissipation of the ground reaction forces through good neuromuscular control is important in this

transition to ensure consistency and safety of the lower limb during landing from a hop (Wikstrom et al, 2004). The spatiotemporal parameters of the urban controls indicate an improved ability to control and dissipate anterior and downward momentum so as to transition smoothly from a dynamic to a static state during a dynamic task. This may therefore indicate that the urban controls displayed relatively better motor control and DPS during the SLH task than the case and rural control groups.

The case group displayed the fastest speed of trial, although this difference was not statistically significant. The females in the case group hopped faster compared to the males within each group. The faster speed adopted by the case group and the females compared to males may indicate poorer postural control as similar findings with regards to hopping speed were found in the study by Parker et al (1993).

Although the hopping task was different to our study, Parker et al (1993) found that younger children (three to seven years old) displayed faster in-place repetitive hopping frequencies compared to older children aged eight to nine years. This was explained as decreased neuromotor development in the younger children as they were unable to slow the hopping frequency so as to efficiently control the momentum of the body and anticipate the timing and amount of external GRF that occur during landing, as the older children were able to do with a slower hopping frequency (Parker et al, 1993). In saying that, it may be deducible that because the case group, and in particular the females of the group, hopped faster, they had more difficulty with control and timing of the task than both the control and male case groups.



## 5.4 Centre of pressure

Higher values of COP parameters are seen to indicate poorer postural stability during dynamic tasks (Birmingham, 2000; Myer et al, 2006; Pau et al, 2015). COP parameters show the amount and speed of movement of the body's COM, and therefore how a person decelerates their body from a dynamic state and controls the movement on the stabilising leg in a static state (Wikstrom et al, 2008). A previous study has examined COP parameters (AP and ML excursions and total area of COP path) in children with FASD and children with ADHD (Kooistra et al, 2009). A static bilateral lower limb task was used in this study to examine COP parameters to evaluate postural stability. The authors found that both children with ADHD and FASD displayed significantly higher COP values in both AP and ML directions compared to a control group, indicating poorer postural stability (Kooistra et al, 2009).

A study conducted by Pau et al (2015) which compared postural stability in a group of 14 to 16 year old soccer players to a group of adult professional soccer players during a bilateral jump to stabilise on one leg, reported values of COP AP displacement of 13cm (youth league) and 11cm (professionals) and ML displacement of 4cm (youth league) and 3.5cm (professionals). The authors suggested that the lower values for COP AP and ML displacements seen in professionals were due to superior experience in recovering postural stability during dynamic tasks (Pau et al, 2015).

The case group in our study showed similar median  $AP_{ROM}$  values (11.37cm) to the professional group in the study by Pau et al (2015) and this was higher than both the

rural control group  $AP_{ROM}$  (9.19cm) and the urban control group  $AP_{ROM}$  (9.81), although this difference was not significant. The higher  $AP_{ROM}$  of the case group is in alignment with the findings of higher  $AP_{ROM}$  values for youth league participants compared to professionals in the study by Pau et al (2015) and therefore may indicate poorer recovery of DPS for the children in the case group compared to the control groups. The faster speed of trial displayed by the case group may also have contributed to the higher COP AP parameters as the children were moving too fast to be able to control and stabilise during the last land on the pressure mat.

In this study, the females had increased  $AP_{vel}$  and  $AP_{ROM}$  values compared to males across all groups. This may be explained by their faster approach speeds than males. This may indicate that faster hopping speeds translates into faster and greater COP movements in the AP direction during the landing and stabilising phase, and may further the idea that females displayed poorer DPS in this task than males.

The differences in the AP direction but not in the ML direction of the COP parameters are to be expected due to the nature of the SLH task, where anterior momentum is the dominating movement throughout the task, and therefore control of the AP movement of the body will be affected more greatly than ML movement to regain stability on the last land.

## 5.5 Time to stability

TTS is a commonly used measure of DPS in dynamic, functional tasks such as hopping and landing to stabilise on one leg (Ross et al, 2009; Wikstrom et al, 2005b; Gribble & Robinson, 2010). Although a force plate is commonly used to determine GRF data in the AP, ML and vertical (V) directions in order to establish TTS, in this study only a pressure mat was available for use. TTS was therefore established using the same principles as when the GRF data is used to determine TTS. In this study, there were no statistically significant differences between groups on TTS, but the case group did show slightly lower values (0.52s) for this parameter compared to the rural control group (0.66s) and the urban control group (0.62s). These values are lower in comparison to those found in studies by DiStefano et al, (2010) and Pau et al (2015).

The study conducted by DiStefano et al (2010) examined postural stability in children between nine and 11 years old following three exercise programmes and reported GRF TTS in the AP and ML directions of a land from a single leg jump from a box onto a force plate. They found TTS values pre-intervention of 2.59s, 2.87s and 2.73s (three intervention groups) in the AP direction and 1.41s, 1.45s and 1.4s in the ML direction. Post-intervention AP TTS values were 2.22s, 1.82s and 2.11s and ML TTS values were 1.39s, 1.42s and 1.47s. Clear improvements (indicated by lower scores) in AP TTS values were seen, but not in the ML direction. The authors attributed this to the task being challenging in the sagittal, but not in the frontal plane (evidenced by faster ML TTS than AP TTS), thereby providing greater room for improvement post-intervention in the AP direction (DiStefano et al, 2010). The study by Pau et al (2015) found mean vertical GRF TTS following a bilateral jump to land and stabilise on one

leg on a force plate to be 1.12s for the youth group and 0.77s in the professional group, furthering the finding of improved DPS in professional soccer players compared to youth league players (Pau et al, 2015).

It is unclear whether the smaller TTS values found in our study are due to the smaller distance (45cm) our participants were required to hop compared to a distance half the child's body height in the study by DiStefano et al (2010) and 90cm in the study by Pau et al (2015); differing calculation methods of TTS; or whether the children in our study were able to stabilise more quickly in comparison to the children in the studies of DiStefano et al (2010) and Pau et al (2015).

## **5.6 Kinematics**

To our knowledge, this is the first study to examine hip, knee and ankle kinematics in the sagittal plane during consecutive forward hopping. Research investigating DPS focusses on a jump/hop and land to stabilise task, and therefore describes the kinematics of the lower limb from slightly before and at IFC of the land to the point when stability has been reached. The next section will therefore discuss the kinematic patterns seen in the children during the movement phase (ie. consecutive hopping), followed by a discussion of landing kinematics with comparisons to previous research.

### 5.6.1 Hopping kinematics and kinematic patterns

Differences between the three groups in this study were found in hip, knee and ankle hopping kinematics. Urban controls adopted the most flexed hip and knee position and jumped with increased plantarflexion at the ankle, as well as moved through the most ankle ROM compared to the other two groups. This movement pattern may indicate better postural stability in the urban controls as the flexed position of the hip and knee lowers the COM of the body and may contribute to better postural control (Gribble & Robinson, 2010).

The fact that the ankle moved through the most ROM in the urban control group, compared to the other groups, may indicate that this joint was used for propulsion of the body, as opposed to the hip and knee extending fully to propel the body upwards and forwards. This finding is therefore in alignment with the spatiotemporal parameters of the urban control group as they propelled their bodies higher through the use of ankle plantarflexion, while keeping the hip and knee in more flexed positions (compared to the case and rural control groups) to control their COM lower and over their feet.

The rural controls displayed similar kinematic patterns at the hip, knee and ankle as the urban control group, however the ankle did not travel through as much ROM in the rural control group as it did in the urban control group. This may indicate that a similar pattern of movement was adopted by both control groups, but the decreased ankle ROM compared to the urban control group indicates that they did not adopt the same propulsion at the ankle and therefore had less time in the air during each hop.

The case group displayed somewhat different kinematics and joint positioning during hopping, whereby they were more extended at the hip and knee and more dorsiflexed at the ankle compared to the control groups. Biomechanically, if the hip and knee are in a more extended position and the ankle dorsiflexed, the body's COM will be held slightly anteriorly. A study by Shimokochi et al (2009) related this anterior position of the body during landing with decreased knee extensor muscle work and increased hip extensor muscle work required to maintain stability during landing.

In alignment with this theory, the case group in our study maintained a more extended hip position during hopping and used increased hip extension for forward propulsion compared to the control groups. This could have potentially contributed to the faster speed in which the case group completed the task, as the COM remained anteriorly displaced and therefore the forward momentum was greater. In terms of postural stability, the greater the hip and knee extension during a hop, the more upright the body is, which raises the COM. This may indicate poorer postural stability as the higher the COM is, the more likely the body is to move uncontrollably and stability will be compromised (Gribble & Robinson, 2010)

### **5.6.2 Landing kinematics**

The three groups in this study displayed somewhat different kinematics when landing onto the pressure mat. Statistically significant differences were observed between the groups for knee and ankle IFC angles. The case group and rural control group landed with significantly more knee flexion ( $28.82^{\circ}$  and  $29.42^{\circ}$  respectively) than the urban controls ( $18.96^{\circ}$ ). In a study by Brazen et al (2010) knee sagittal angles were recorded at IFC of landing from a height in healthy 17 to 24 year olds before and

after a fatiguing protocol. Pre-fatigued mean IFC knee angles were  $39.38^{\circ}$  in women and  $35.47^{\circ}$  in men and post-fatigued mean IFC knee angles were  $46.65^{\circ}$  in women and  $41.11^{\circ}$  in men. The authors suggested that the increase in IFC knee flexion post-fatigue was due to the musculature of the lower limbs being unable to hold the body effectively in an upright position. Similar IFC knee flexion values, but negligible differences between groups, were found by Schmitz and colleagues (2007), who investigated sex differences in lower limb landing biomechanics. Knee flexion angles at IFC were  $42.5^{\circ}$  for females and  $38.9^{\circ}$  for men.

The values for knee flexion at IFC are considerably larger in the two studies by Brazen et al (2010) and Schmitz et al (2007) compared to those found in our study. The differences in IFC angles may be explained by the different tasks performed in the studies. Participants in the studies by Brazen et al (2010) and Schmitz et al (2007) stepped off a raised platform (36cm and 30cm respectively) and landed on one leg. It has been shown that landing from greater heights results in greater hip and knee flexion values (McNitt-Gray, 1993) and this could explain the larger values of knee flexion at IFC compared to our study where children hopped consecutively on the floor. The differences could also be explained as the difference between landing strategies or landing requirements of adults and children, however no literature to our knowledge is available for landing kinematics in children and therefore this remains to be investigated.

In terms of ankle IFC angles, the urban controls landed in a statistically significant more plantarflexed position ( $-3.71^{\circ}$ ) than rural controls ( $3.56^{\circ}$ ) and cases ( $7.36^{\circ}$ ). This may indicate that the urban control group used the ankle joint as the first shock-

absorber during landing by increasing the work of the plantarflexors and thereby decreasing demands on the proximal joints, i.e. the hip and knee (Shimokochi et al, 2009).

The IFC plantarflexion values found in our study are much smaller in comparison to those found in studies conducted by De Ridder et al (2015a) and Gribble and Robinson (2009). De Ridder et al (2015a) observed IFC plantarflexion angles of  $-36.1^{\circ}$  in subjects with no ankle taping and  $-32.8^{\circ}$  in subjects with ankle taping. Gribble & Robinson (2009) found IFC plantarflexion angles of  $-36.1^{\circ}$  in control groups and  $-36.14^{\circ}$  in subjects with chronic ankle instability. The smaller values found in our study may again be attributed to differences in the tasks, as the participants in the study by De Ridder et al (2015a) had to jump over a 30cm hurdle to land on one leg, and those in the study by Gribble and Robinson (2009) jumped to 50% of their maximum vertical jump height before landing on one leg. Therefore, in both previous studies participants descended from a higher vertical height than in our study, thereby requiring greater ankle plantarflexion at IFC in an attempt to dissipate GRF by lowering the body down over a wider ROM of the ankle (Decker et al, 2003).

Maximum (peak) angles during landing differed between the three groups. Urban controls displayed statistically significant higher maximum hip flexion values ( $30.04^{\circ}$ ) than both the rural control group ( $25.76^{\circ}$ ) and the case group ( $21.43^{\circ}$ ). The study by Gribble and Robinson (2009) found similar values for peak hip flexion in, although negligible differences between, participants with chronic ankle instability ( $30.83^{\circ}$ ) and participants with stable ankles ( $29.9^{\circ}$ ). Rural and urban control groups also displayed



greater maximum knee flexion values ( $46.74^{\circ}$  and  $46.09^{\circ}$  respectively) during landing compared to the case group ( $37.15^{\circ}$ ). The greater maximum hip flexion observed in the urban control group, and the greater maximum knee flexion angles seen in both control groups, compared to the case group, may indicate improved ability to lower the COM during landing so as to ensure stability is maintained (Gribble & Robinson, 2009).

Wikstrom et al (2004) found similar, but slightly higher maximum knee flexion values before and after fatiguing protocols in healthy subjects. The pre-fatiguing protocol maximum knee flexion angles during a land from a jump protocol were  $50^{\circ}$  and  $52^{\circ}$  (two different fatiguing protocol groups) and there was only one degree of positive change found after the fatiguing protocols. Therefore, for knee and ankle IFC angles our study produced different results compared to typical jump-land protocols, but the maximum hip and knee angles observed during our landing protocol were comparable to previous literature.

## **5.7 Hopping strategies**

Considering all the findings, a picture does emerge with regards to the hopping and landing strategies of the different groups of children. The urban control group hopped in a more flexed position of the lower limb, keeping their COM lower to maintain stability. Travelling through greater ankle ROM during hopping enabled this group to hop in a way that minimised excessive anterior momentum thereby making the movement easier to control.

The urban control group landed on the pressure mat with a slightly more extended knee and with the ankle in plantarflexion in order to accept the weight of their bodies onto the forefoot. The slightly more extended knee position in this group may have been adopted so as to allow for an increased plantarflexor position upon landing. This manifestation may have been a strategy to create a longer landing time and potential use of the most ROM of the lower limb to absorb and dissipate the shock experienced during landing (Gribble & Robinson, 2010; Decker et al, 2003; McNitt-Gray, 1993). Shimokochi et al (2009) emphasized the importance of the shock-absorption function of the plantarflexors during landing, so as to decrease the stress and internal joint moments onto the knee. Therefore, increased plantarflexion at IFC, together with greater maximum angles at the hip and the knee during landing, reflects a strategy that dissipates landing forces more efficiently, for better control and protection of the joints and lower limb structures from the ground reaction forces experienced during landing (Wikstrom et al, 2004; Brazen et al, 2010; Decker et al, 2003).

The urban controls displayed lower values of  $AP_{vel}$  and  $AP_{ROM}$  during landing to stabilise on the pressure mat compared to the case group. This may be attributed to the work of the distal joint and muscles (ankle and plantarflexors) dissipating the impact of landing so as to decrease the work on the proximal joints and this could assist in maintaining the body's COM more closely over the base of support (Schmitz et al, 2007).

The rural control group made use of a similar hopping strategy to the urban control group. They remained in a flexed position of the lower limb throughout the hops to keep their COM relatively low. They did not however use the ankle to predominantly propel themselves upwards as the urban group did but instead used a fair amount of hip and knee extension to hop forwards. Upon landing, the rural controls held their ankles in a more neutral position throughout weight acceptance. Instead of using the plantarflexors for shock-absorption, flexion of the hip and knee and the major muscles around these joints were responsible for eccentrically decelerating and lowering the body into a stable position on one leg. Similarly to the urban control group, the rural controls moved into higher maximum angles of the hip and knee during landing and were therefore able to decelerate and control their COP movement in both AP and ML directions so as to stabilise effectively on one leg.

The case group seemed to adopt a different hopping strategy, one in which they kept the lower limb joints slightly stiffer and more extended throughout the task. Due to the decreased hip and knee flexion and ankle plantarflexion and the increased hip extension ROM during hopping compared to the control groups, it appears that the hip extensors were primarily used to propel the body forward. This strategy where the lower leg joints (ie. the knee and ankle) are held somewhat rigidly and the major hip musculature is used to stabilise and move may be indicative of a compensatory strategy for a postural stability limitation. This “hip strategy,” where adjustments to the COM during a dynamic task are achieved through movement at the hip anteriorly or posteriorly in space, has been linked to impaired postural stability function (Pintsaar et al, 1996; De Ridder et al, 2015a).

Having adopted this more extended and upright posture during hopping, when the case group landed on the mat to stabilise, the knee was flexed more than the control groups possibly in an attempt to lower the COM and reduce the impact of the land on the body. The hip, however, was in a more extended position at IFC compared to the control groups and this may have contributed to their COM remaining higher above the base of support. As stated previously, a higher COM is most likely to result in poorer stability and this was displayed by the increased  $AP_{vel}$  and  $AP_{ROM}$  values observed in the case group while stabilising on the pressure mat.

During landing on the pressure mat, the case group showed lower maximum angles at all three joints compared to the other groups. This indicates that a stiffer and more upright position was maintained during landing and that the case group did not use flexion of the hip and knee to absorb or dissipate the ground reaction forces or forward momentum of the body. This may indicate a decreased ability to decelerate the body eccentrically in a controlled manner during landing to stabilise (Wikstrom et al, 2004).

## Chapter 6

### LIMITATIONS AND RECOMMENDATIONS

#### 6.1 Limitations

A limitation of the study could be the relatively small number of trials available for certain parameters in the two groups from the rural study compared to the urban study group. This was due to technical problems with the motion analysis systems, particularly the Xsens system. Further trials were excluded from the COP and TTS analyses as participants shuffled on the pressure mat during landing. Despite giving participants three to five practice attempts (no more being afforded so as to limit learning or fatigue effects), some were simply unable to execute the task without shuffling and therefore the trials had to be discarded. Having small datasets in certain groups could limit the generalisability of the results and conclusions drawn from this study.

The use of two different measurement systems in this study (the Xsens for the rural groups and the MyoMotion for the urban group) could be considered a further limitation but concurrent validity testing was conducted with a small group of children and the results favoured the comparability of the two systems in terms of the spatiotemporal parameters. Though concurrent validity testing could not be performed for the kinematic parameters due to sensor placement difficulties (as explained in section 3.14.7 in the methods) the individual measurement instruments have excellent psychometric properties when compared to the VICON system (Balasubramanian, 2013; Zhang et al, 2013; Cloete & Scheffer, 2008). Taking this

into consideration, as well as the fact that the MyoMotion is a newer and more sophisticated system, allowing for less technical errors and improved accuracy compared to the Xsens, it was chosen for use in the urban study.

A further potential limitation is that the sampling process was not as rigorous in the urban study compared to the rural study, in which a diagnostic team had made the relevant diagnoses of FASD or no PAE (May et al, 2013). Two of the four schools from which children were recruited in the urban study were in lower SES areas in the Cape Metropole (informal settlements) and this has been linked with a higher maternal alcohol consumption level and FASD (May et al, 2005; 2008). Therefore, because we aimed at recruiting typically developed children in the urban study, all potential exclusion criteria (as explained in section 3.10.2 in the methods) were considered to lessen the possibility of children with PAE or developmental problems being included in the study.

## **6.2 Recommendations**

Consecutive SLH may have been too difficult a task for some of the children included in this study which resulted in a number of data exclusions. Future research could perhaps examine fewer consecutive hops or even one hop over a distance or a height, as is common in SLH research. In this way the human motion analysis system and pressure mat could still be used to examine the kinematics and DPS, thereby maintaining the sensitivity of the gross motor assessment to detect impairments, but the task would not be too difficult so as to exclude the study population.

In order to limit the loss of COP and TTS trials, future research may consider implementing measures such as marking on the pressure mat where the child should place his/her foot on landing. This may assist the participant in landing in the correct position, as well as limiting the shuffling action.

With regards to testing the psychometric properties between two measuring systems it could be recommended to test predictive validity and to use walking as the chosen task, as walking is more reproducible than hopping. In doing this, the problems encountered with the placement of the two systems' sensors on a child's body (required for concurrent validity testing) may be avoided and the two systems could be tested for predictive validity for all spatiotemporal and kinematic parameters.

## Chapter 7

### CONCLUSION

This study has described DPS and kinematics during a consecutive SLH task in children aged nine years old with and without FASD. Through the use of multiple outcome parameters and motion and video analysis tools we have been able to describe this motor task and how it relates to DPS objectively and with a certain depth. This study has identified different postural control and motor strategies adopted for single leg hopping and landing to stabilise between typically developed children and children with FASD. The case group hopped faster and spent less time in contact with the ground and in the air compared to urban controls. The case group adopted a more extended position of the lower limbs during hopping and did not move into as much flexion at the hip and knee during landing compared to the control groups, therefore displaying a stiffer landing strategy. The case group also performed worse in terms of COP AP parameters compared to the control groups. All of these factors may be an indication of impaired DPS in the case group compared to the control groups.

This is the first study conducted, nationally and internationally, on children with and without FASD using human motion analysis and a pressure mat to investigate a gross motor function task which includes all the requirements of DPS, motor planning and coordination. The enormity of the prevalence of FASD in South Africa, and the life-long affects and disabilities children and adults with FASD experience, requires research to investigate and explore the commonly found impairments in persons with this disorder. Understanding the gross motor impairments found in



children with FASD, such as impaired postural stability and poor coordination and motor planning, will enable physiotherapists and occupational therapists to provide more precise and effective treatments to assist children with FASD in coping better with the physical demands of daily life.

The need for further research in this field is warranted. A better understanding of motor function and the underlying impairments thereof, in children with FASD, could have positive implications in terms of more timeous diagnoses and referrals and the development and implementation of evidence-based treatments.

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## Addenda

### Addendum A

#### Ethical approval (rural study)



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jou kennisvenoot • your knowledge partner

#### Approved with Stipulations New Application

12-Dec-2013  
Brink, Yolandi Y

**Ethics Reference #:** N13/10/140

**Title:** The postural stability and motor control of children with Foetal Alcohol Spectrum Disorders: A pilot study

Dear Mrs. Yolandi Brink,

The **New Application** received on **30-Oct-2013**, was reviewed by Health Research Ethics Committee 2 via Committee Review procedures on **20-Nov-2013**.

Please note the following information about your approved research protocol:

Protocol Approval Period: **20-Nov-2013 -20-Nov-2014**

**Present Committee Members:**

Barsdorf, Nicola  
Blaauw, Renee R  
Botha, Matthys MH  
Botha, Philip PR  
Davids, Mertrude MA  
De Roubaix, Malcolm JAM  
Edwards, C E  
Etoe, Sheila SL  
Kruger, Mariana M  
Mills, Lize L  
Rohland, Elvira EL  
Rosenkranz, Bernd B  
Verster, Gerrit GC  
Willett, Derrick DWE

The Stipulations of your ethics approval are as follows:

**Kindly correct the English informed consent form (ICF) by addressing the following issues:**

1. Kindly remove any mention of study doctor, since this is not a clinical study
2. Please explain the meaning of motor development
3. We are unsure if the assent part should be part of this form, or separate. At the moment it is given twice.

**Kindly correct the Afrikaans informed consent form (ICF) by addressing the following issues:**

4. Gebruik die korrekte naam van die Departement.
5. Verduidelik die terme 'motorise ontwikkeling' en 'posturale stabiliteit'.
6. Daar is heelwat spelfoute wat gekorrigeer moet word.
7. Gebruik asseblief deurgaans of 'u' of 'jy / jou'.

**Kindly correct the English Assent form by addressing the following issue:**

8. 'Who can I talk to about the study' delete the '?' after the name of the school principle.

**Kindly correct the Afrikaans Assent form by addressing the following issues:**

9. Gebruik die korrekte naam van die Departement.
10. Daar is heelwat spelfoute wat gekorrigeer moet word.
11. 'Wat sal in hierdie studie met my gebeur' verander 'hy' na 'jy'.
12. 'Met wie kan ek oor die studie praat' verwyder die '?' na die skoolhoof se naam.

Please remember to use your **protocol number** (N13/10/140) on any documents or correspondence with the HREC concerning your research protocol.

Please note that the HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

**After Ethical Review:**

Please note a template of the progress report is obtainable on [www.sun.ac.za/rds](http://www.sun.ac.za/rds) and should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.

Translation of the consent document to the language applicable to the study participants should be submitted.

Federal Wide Assurance Number: 00001372

Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

**Provincial and City of Cape Town Approval**

Please note that for research at a primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of Health ([healthres@pgwc.gov.za](mailto:healthres@pgwc.gov.za) Tel: +27 21 483 9907) and Dr Helene Visser at City Health ([Helene.Visser@capetown.gov.za](mailto:Helene.Visser@capetown.gov.za) Tel: +27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.

For standard HREC forms and documents please visit: [www.sun.ac.za/rds](http://www.sun.ac.za/rds)

If you have any questions or need further assistance, please contact the HREC office at 0219389207.

**Included Documents:**

Application Form  
Declaration - Seedat  
Declaration - Marais  
Declaration - Louw  
Declaration - Grimmer  
CV - Louw  
Declaration - Brink  
CV - Grimmer  
Declaration - Cockcroft  
Checklist  
CV - Seedat  
CV - Cockcroft  
Protocol, Synopsis & Consent/Assent Forms  
CV - Marais  
CV - Brink

Sincerely,

Mertrude Davids  
HREC Coordinator  
Health Research Ethics Committee 2



# Investigator Responsibilities

## Protection of Human Research Participants

Some of the responsibilities investigators have when conducting research involving human participants are listed below:

1. Conducting the Research. You are responsible for making sure that the research is conducted according to the HREC approved research protocol. You are also responsible for the actions of all your co-investigators and research staff involved with this research.
2. Participant Enrolment. You may not recruit or enrol participants prior to the HREC approval date or after the expiration date of HREC approval. All recruitment materials for any form of media must be approved by the HREC prior to their use. If you need to recruit more participants than was noted in your HREC approval letter, you must submit an amendment requesting an increase in the number of participants.
3. Informed Consent. You are responsible for obtaining and documenting effective informed consent using **only** the HREC-approved consent documents, and for ensuring that no human participants are involved in research prior to obtaining their informed consent. Please give all participants copies of the signed informed consent documents. Keep the originals in your secured research files for at least fifteen (15) years.
4. Continuing Review. The HREC must review and approve all HREC-approved research protocols at intervals appropriate to the degree of risk but not less than once per year. There is **no grace period**. Prior to the date on which the HREC approval of the research expires, **it is your responsibility to submit the continuing review report in a timely fashion to ensure a lapse in HREC approval does not occur**. If HREC approval of your research lapses, you must stop new participant enrolment, and contact the HREC office immediately.
5. Amendments and Changes. If you wish to amend or change any aspect of your research (such as research design, interventions or procedures, number of participants, participant population, informed consent document, instruments, surveys or recruiting material), you must submit the amendment to the HREC for review using the current Amendment Form. You **may not initiate** any amendments or changes to your research without first obtaining written HREC review and approval. The **only exception** is when it is necessary to eliminate apparent immediate hazards to participants and the HREC should be immediately informed of this necessity.
6. Adverse or Unanticipated Events. Any serious adverse events, participant complaints, and all unanticipated problems that involve risks to participants or others, as well as any research-related injuries, occurring at this institution or at other performance sites must be reported to the HREC within **five (5) days** of discovery of the incident. You must also report any instances of serious or continuing problems, or non-compliance with the HRECs requirements for protecting human research participants. The only exception to this policy is that the death of a research participant must be reported in accordance with the Stellenbosch University Health Research Ethics Committee Standard Operating Procedures [www.sun025.sun.ac.za/portal/page/portal/Health\\_Sciences/English/Centres%20and%20Institutions/Research\\_Development\\_Support/Ethics/Application\\_package](http://www.sun025.sun.ac.za/portal/page/portal/Health_Sciences/English/Centres%20and%20Institutions/Research_Development_Support/Ethics/Application_package) All reportable events should be submitted to the HREC using the Serious Adverse Event Report Form.
7. Research Record Keeping. You must keep the following research-related records, at a minimum, in a secure location for a minimum of fifteen years: the HREC approved research protocol and all amendments; all informed consent documents; recruiting materials; continuing review reports; adverse or unanticipated events; and all correspondence from the HREC
8. Reports to the MCC and Sponsor. When you submit the required annual report to the MCC or you submit required reports to your sponsor, you must provide a copy of that report to the HREC. You may submit the report at the time of continuing HREC review.
9. Provision of Emergency Medical Care. When a physician provides emergency medical care to a participant without prior HREC review and approval, to the extent permitted by law, such activities will not be recognised as research nor will the data obtained by any such activities should it be used in support of research.
10. Final reports. When you have completed (no further participant enrolment, interactions, interventions or data analysis) or stopped work on your research, you must submit a Final Report to the HREC.
11. On-Site Evaluations, MCC Inspections, or Audits. If you are notified that your research will be reviewed or audited by the MCC, the sponsor, any other external agency or any internal group, you must inform the HREC immediately of the impending audit/evaluation.

## Addendum B

### Database search strategies

#### Search Strategy A

FASD and Gross Motor Function			
Database	Search Terms	No. of hits	Limits/Filters
Pubmed	1. FASD + motor function + children	90	Humans
	2. FASD + motor control + children	55	
	3. FASD + postural control + children	11	
	4. FASD + balance + children	33	
	5. FASD + children + South Africa	67	
	Total		
Scopus	As above:		None
	1.	115	
	2.	126	
	3.	17	
	4.	478	
	5.	69	
Total		805	
Science Direct	As above:		None
	1.	287	
	2.	159	
	3.	44	
	4.	701	
	5.	117	
Total		1308	
EbscoHost	As above:		None
	1.	26	
	2.	31	
	3.	4	
	4.	75	
	5.	92	
Total		228	
Proquest Medical Library	As above:		Humans, preschool age, children, adolescents
	1.	360	
	2.	402	
	3.	26	
	4.	225	
	5.	35	
Total		1048	
Total number of articles on motor function and FASD: 3645			



**Search Strategy B**

<b>Single leg Hop</b>			
<b>Database</b>	<b>Search Terms</b>	<b>No. of hits</b>	<b>Limits/Filters</b>
<b>Pubmed</b>	1. Force plate + single leg hop	8	Humans
	2. Force plate + one leg hop	1	
	3. Force plate + jump	221	
	4. Single leg hop + stability	41	
	5. Single leg hop + biomechanics	18	
	6. Single leg hop + motion analysis	17	
<b>Total</b>		<b>306</b>	
<b>Scopus</b>	As above:		None
	1.	24	
	2.	5	
	3.	640	
	4.	175	
	5.	186	
	6.	25	
<b>Total</b>		<b>1055</b>	
<b>Science Direct</b>	As above:		Relevant fields of science
	1.	42	
	2.	28	
	3.	877	
	4.	211	
	5.	135	
	6.	27	
<b>Total</b>		<b>1320</b>	
<b>EbscoHost</b>	As above:		Relevant databases
	1.	8	
	2.	0	
	3.	839	
	4.	115	
	5.	73	
	6.	9	
<b>Total</b>		<b>1044</b>	
<b>Proquest Medical Library</b>	As above:		Humans, children, adults adolescents, English
	1.	56	
	2.	36	
	3.	229	
	4.	53	
	5.	87	
	6.	127	
<b>Total</b>		<b>588</b>	
<b>Total number of articles on single leg hop tests: 4313</b>			

## Addendum C

### WCED letter of approval (rural study)



Education

[Audrey.wyngaard2@pgwc.gov.za](mailto:Audrey.wyngaard2@pgwc.gov.za)

tel: +27 021 467 9272

Fax: 0865902282

Private Bag x9114, Cape Town, 8000

wced.wcape.gov.za

**REFERENCE:** 20140211-24550

**ENQUIRIES:** Dr A T Wyngaard

Dr Yolandi Brink  
Division of Physiotherapy, Department of Interdisciplinary Health and Sciences  
Faculty of Medicine & Health Sciences  
Stellenbosch University  
PO Box 19063  
Tygerberg  
7505

**Dear Dr Yolandi Brink**

#### **RESEARCH PROPOSAL: THE POSTURAL STABILITY AND MOTOR CONTROL OF CHILDREN WITH FOETAL ALCOHOL SPECTRUM DISORDERS: A PILOT STUDY**

Your application to conduct the above-mentioned research in schools in the Western Cape has been approved subject to the following conditions:

1. Principals, educators and learners are under no obligation to assist you in your investigation.
2. Principals, educators, learners and schools should not be identifiable in any way from the results of the investigation.
3. You make all the arrangements concerning your investigation.
4. Educators' programmes are not to be interrupted.
5. The Study is to be conducted from **27 February 2014 till 30 June 2014**
6. No research can be conducted during the fourth term as schools are preparing and finalizing syllabi for examinations (October to December).
7. Should you wish to extend the period of your survey, please contact Dr A.T Wyngaard at the contact numbers above quoting the reference number?
8. A photocopy of this letter is submitted to the principal where the intended research is to be conducted.
9. Your research will be limited to the list of schools as forwarded to the Western Cape Education Department.
10. A brief summary of the content, findings and recommendations is provided to the Director: Research Services.
11. The Department receives a copy of the completed report/dissertation/thesis addressed to:

**The Director: Research Services  
Western Cape Education Department  
Private Bag X9114  
CAPE TOWN  
8000**

We wish you success in your research.

Kind regards.

Signed: Dr Audrey T Wyngaard

**Directorate: Research**

## Addendum D

### WCED letter of approval (urban study)



[Audrey.wyngaard@westerncape.gov.za](mailto:Audrey.wyngaard@westerncape.gov.za)

tel: +27 021 467 9272

Fax: 0865902282

Private Bag x9114, Cape Town, 8000

wced.wcape.gov.za

**REFERENCE:** 20160211- 7644

**ENQUIRIES:** Dr A T Wyngaard

Ms Keryn Moore  
4 Waverley Close  
Constantia  
7806

**Dear Ms Keryn Moore**

**RESEARCH PROPOSAL: SINGLE-LEG HOPPING IN CHILDREN WITH AND WITHOUT FETAL ALCOHOL SPECTRUM DISORDER: A DESCRIPTIVE STUDY OF POSTURAL STABILITY AND KINEMATICS**

Your application to conduct the above-mentioned research in schools in the Western Cape has been approved subject to the following conditions:

1. Principals, educators and learners are under no obligation to assist you in your investigation.
2. Principals, educators, learners and schools should not be identifiable in any way from the results of the investigation.
3. You make all the arrangements concerning your investigation.
4. Educators' programmes are not to be interrupted.
5. The Study is to be conducted from **15 February 2016 till 30 September 2016**
6. No research can be conducted during the fourth term as schools are preparing and finalizing syllabi for examinations (October to December).
7. Should you wish to extend the period of your survey, please contact Dr A.T Wyngaard at the contact numbers above quoting the reference number?
8. A photocopy of this letter is submitted to the principal where the intended research is to be conducted.
9. Your research will be limited to the list of schools as forwarded to the Western Cape Education Department.
10. A brief summary of the content, findings and recommendations is provided to the Director: Research Services.
11. The Department receives a copy of the completed report/dissertation/thesis addressed to:

**The Director: Research Services  
Western Cape Education Department  
Private Bag X9114  
CAPE TOWN  
8000**

We wish you success in your research.

Kind regards.

Signed: Dr Audrey T Wyngaard

**Directorate: Research**

**DATE: 19 May 2016**

## Addendum E

### Information letter and informed consent for principals of schools

## PARTICIPANT INFORMATION LEAFLET

### TITLE OF THE RESEARCH PROJECT:

“Single leg hopping in children with and without Fetal Alcohol Spectrum Disorder: A descriptive study of postural stability and kinematics”

**REFERENCE NUMBER: S15/09/207**

### PRINCIPAL INVESTIGATOR:

Keryn Moore

### ADDRESS:

Physiotherapy Department, Faculty of Medicine and Health Sciences, Stellenbosch University

### CONTACT NUMBER:

0741019859

Dear Principal

My name is Keryn Moore and I am a physiotherapist doing a Masters' thesis on movement analysis of children with and without Fetal Alcohol Spectrum Disorder (FASD). I would like to invite your school to participate in a research project that aims to describe single leg hopping in children with and without FASD by looking at postural stability and movement kinematics. This section of the data collection, in which your school will be involved, will only include typically developed nine-year-old children.

Please take some time to read the information presented here, which will explain the details of this project and contact me if you require further explanation or clarification of any aspect of the study. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee (HREC) at Stellenbosch University** and will be conducted according to accepted and applicable National and International ethical guidelines and principles, including those of the international Declaration of Helsinki 2013.

This study has randomly chosen four schools, one in each of the school districts in the Cape Metropole. With your consent, I would like to obtain a list of all nine-year-old children in the school and randomly select twenty to participate in the study. Parents/guardians will be given an information leaflet about the study and we will obtain written informed consent from the parents/guardians and written informed assent from the children. I will then randomly select eight participants from those who have consented and been successfully screened through a health questionnaire. The testing will take place in a suitable venue at your school, during school hours, so the children do not have to travel anywhere. The testing procedure will take approximately 20 minutes for each child and I will aim to test all the children in your school in one morning.

Testing procedure:

Children's height, weight and head circumference measurements will be recorded on the day of testing. Small inertial sensors will be placed on the children's legs and pelvis. The children will then hop on one leg five times in a row in squares marked off on the floor. They will land and balance on a pressure mat at the end of the five squares. They will do this on both the right and left legs.

The data from the inertial sensors and the pressure mat will be collected and stored on a program on my computer for analysis. Using this information I will be able to describe in detail how the children perform this activity in terms of lower limb kinematics, as well as postural stability when they land. This data will then be compared to data that was previously collected by my supervisor, Dr Y. Brink, in 2014. This previous data collection included a group of nine-year-old children with FASD (cases) and a group of nine-year-old children without FASD (controls). Therefore, this study, in which I am the principal investigator, will compare data from typically developed children in the Cape Metropole to the historical data from children with FASD.

South Africa, and the Western Cape in particular, have the highest prevalence rates of FASD in the world and it is therefore an important area of research at present. This study will help to establish whether children with FASD have motor function and postural stability impairments. This can aid in better future diagnosis and evidence-based treatment for these children, so as to improve their overall development and quality of life.

Confidentiality:

The children's information will be stored on a password-protected computer which only myself, Dr Brink and the biomedical engineer helping with the project will have access to. Your school and the children's information will remain anonymous in the final thesis. Once the thesis has been accepted, all results will be made available to you in the form of a published scientific paper.

**If you are willing to participate in this study please sign the attached Declaration of Consent and hand to the principle investigator, Keryn Moore.**

Yours sincerely

Keryn Moore (Principal Investigator)

## Declaration by participant (school principal)

By signing below, I ..... agree to allow nine-year-old learners from..... (school) to take part in a research study entitled “**Single leg hopping in children with and without Fetal Alcohol Spectrum Disorder: A descriptive study of postural stability and kinematics.**”

I declare that:

- I have read the attached information leaflet and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.

Signed at (*place*) ..... On (*date*) ..... 2016.

.....

**Signature of participant**

## Addendum F

### Informed consent letter for parents/guardians

## PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

### TITLE OF THE RESEARCH PROJECT:

“Single leg hopping in children with and without Fetal Alcohol Spectrum Disorder: A descriptive study of postural control and kinematics.”

### REFERENCE NUMBER: S15/09/207

### PRINCIPAL INVESTIGATOR:

Keryn Moore

### ADDRESS:

Physiotherapy Department, Faculty of Medicine and Health Sciences, Stellenbosch University

### CONTACT NUMBER:

0741019859

Your child is being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the study staff any questions about any part of this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way whatsoever. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Health Research Ethics Committee at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki (2013), South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

### What is this research study all about?

This study will take place at the school where your child is attending, at a time during school hours that has been agreed upon by the school principal. Your child is one of twenty nine-year-old children in the school that have been randomly selected and invited to participate in the study. Only eight children, of those that decide to participate, will then be randomly selected to actually participate in the study. This means that if you do decide to give consent for your child to participate, there is a chance that your child will not be included in the study.

The study will describe how typically developed children perform the task of single leg hopping. We will look at how their legs and body move during the activity, as well as how they land and balance on one leg. We are doing this to get more information on how children perform this task so that we can compare typically developed children to children who have Fetal Alcohol Spectrum Disorder (FASD). The part of the study looking at children with Fetal Alcohol Spectrum Disorder has already been completed in 2014.

### **What is Fetal Alcohol Spectrum Disorder (FASD)?**

FASD is a disorder that affects some children whose mothers consumed alcohol while they were pregnant. These children often display problems with memory, attention, learning and movement.

### **Procedures**

All testing procedures will take place at your child's school during school hours. Your child's height, weight and head circumference will be measured before doing the task. These measurements will help us when we are describing the data. Your child will be asked to hop five times in a row in squares marked on the floor. He/she will land in the last block and have to try and balance for three to five seconds on a mat. The mat has sensors built in to show us how his/her foot is moving when he/she lands in the last block. Your child will be wearing small sensors on parts of his/her legs which are attached with straps. These will allow us to measure how his/her legs and joints move during the task.

### **Why have you been invited to participate?**

Your child has been asked to participate in this study so that we can gain more information about how typically developed children move when they are hopping on one leg. This will help us to compare groups of children and better understand the potential problems that children with FASD may have with movement and postural stability.

### **What will your responsibilities be?**

If you do consent to the study, you will be asked to complete a short health questionnaire regarding your and your child's health. This questionnaire will be sent home with your child for you to complete and your child can return it to the research team prior to the start of the study. Since the testing will take place during school hours, you will not be required to be there.

### **Will you benefit from taking part in this research?**

You or your child will have no direct benefits from participating in the study. However, this study forms part of a bigger research project on movement and balance in children with FASD. By gaining more information through this type of study, we hope to better understand the problems that children with FASD face so that we can diagnose and treat this disorder better in the future.

### **Are there any risks involved in your child taking part in this research?**

There are no direct risks to your child. We will make sure the testing venue is comfortable and safe for your child and your child will have many opportunities to complete the task so that they feel comfortable with it.



### Who will have access to your child's information?

All measurements and data obtained from your child will remain confidential. Only the principal researcher and the biomedical engineer (over-seeing the data collection process) will have access to the information. If the information is used in the Master's thesis, your child's information and identity will remain anonymous.

### What will happen in the unlikely event of some form of injury occurring as a direct result of your child taking part in this research study?

If your child is injured while performing the single leg hopping task, a registered physiotherapist (the principal researcher) will be able to attend to your child immediately. The school's standard procedures will be followed thereafter.

### Will you be paid to take part in this study and are there any costs involved?

No, you will not be paid to take part in the study, but your child will receive a small snack hamper as a thank-you after the testing procedure. There will be no costs involved for you as the study will take place during school hours.

### Is there anything else that you should know or do?

- You can contact the Health Research Ethics Committee at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by your principal researcher.
- You will receive a copy of this information and consent form for your own records.

## Declaration by participant

By signing below, I ..... agree to take part in a research study entitled "*Single leg hopping in children with and without Fetal Alcohol Spectrum Disorder: A descriptive study of postural stability and kinematics.*"

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.

Signed at (*place*) ..... on (*date*) ..... 2016.

.....  
Signature of participant

.....  
Signature of witness

## Declaration by investigator

I (*name*) ..... declare that:

- I explained the information in this document to .....
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did/did not use an interpreter. (*If an interpreter is used then the interpreter must sign the declaration below.*)

Signed at (*place*) ..... on (*date*) ..... 2016.

.....  
Signature of investigator

.....  
Signature of witness

## Declaration by interpreter

I (*name*) ..... declare that:

- I assisted the investigator (*name*) ..... to explain the information in this document to (*name of participant*) ..... using the language medium of Afrikaans/Xhosa.
- We encouraged him/her to ask questions and took adequate time to answer them.
- I conveyed a factually correct version of what was related to me.
- I am satisfied that the participant fully understands the content of this informed consent document and has had all his/her question satisfactorily answered.

Signed at (*place*) ..... on (*date*) ..... 2016.

.....  
Signature of interpreter

.....  
Signature of witness

## Addendum G

### Informed assent letter for children

	<b>STELLENBOSCH UNIVERSITY</b> <b>FACULTY OF HEALTH SCIENCES</b>	
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## PARTICIPANT INFORMATION LEAFLET AND ASSENT FORM



### TITLE OF THE RESEARCH PROJECT:

“Describing how children hop on one leg.”

### RESEARCHERS NAME(S):

Keryn Moore

### ADDRESS:

Physiotherapy Department, Faculty of Medicine and Health Sciences, Stellenbosch University.

### CONTACT NUMBER:

0741019859

### What is RESEARCH?

**Research is something we do to find new knowledge about the way things (and people) work. We use research projects or studies to help us find out more about disease or illness. Research also helps us to find better ways of helping, or treating children who are sick.**

### What is this research project all about?

This project is going to describe how different children hop on one leg. This is so we can understand how the body moves and balances while doing this task.

**Why have I been invited to take part in this research project?**

You have been invited to be a part of this research so that we can understand how our body's move and balance while hopping. Hopping is an important activity because you do it while playing and dancing and doing other things. If we look at how you hop on one leg we can try and understand why other children have problems with fun activities like hopping.

**Who is doing the research?**

My name is Keryn and I am doing this project as a part of my university degree.

**What will happen to me in this study?**

If you decide to take part in this project we will come to your school during school time. We will first take your height and weight and then measure around your head with a tape measure.

You will have small sensors strapped to parts of your legs. These are so that we can look at how your legs are moving. You will hop on one leg five times in a row in squares and land in the last block. When you land in the last block you must try and balance on that leg for five seconds. You will first hop on your right leg, then on your left leg.

**Can anything bad happen to me?**

The only bad thing that could happen is if you trip or fall while doing the hopping. If this does happen we will be there to help you.

**Can anything good happen to me?**

Nothing good can happen directly to you, but if you take part you are helping us to understand how children do tasks like hopping.

**Will anyone know I am in the study?**

Myself and the other researchers helping me with the project will know you are in the study, but we won't use your name or show any one else your information. This is so your information stays private.

**Who can I talk to about the study?**

You can talk to both the researchers any time if you have any questions or problems.

Keryn Moore: 0741019859

Yolandi Brink: 0735643557

**What if I do not want to do this?**

If you don't want to be a part of this research you don't have to say yes. Even if your parents say yes for you, you can still say no and you don't have to do it.

If you do want to do it but change your mind at any time you can always tell us and you don't have to continue. You will not get in trouble if you say no or if you don't want to continue in the project at any time.

Do you understand this research study and are you willing to take part in it?

YES

NO

Has the researcher answered all your questions?

YES

NO

Do you understand that you can pull out of the study at any time?

YES

NO

\_\_\_\_\_  
Signature of Child

\_\_\_\_\_  
Date

## Addendum H

### Health questionnaire

#### Health Questionnaire

Please take a few minutes to read and answer the following questions. These questions are to help us determine whether your child can be included in the study  
**“Single leg hopping in children with and without Fetal Alcohol Spectrum Disorder: A descriptive study of postural stability and kinematics.”**

All questions refer only to the child that is being asked to participate in this study.  
 All answers are confidential and will not be shown to anyone other than the principal researcher.

#### 1. How old were you when you fell pregnant?

*Please tick appropriate box*

15-20	21-25	26-30	31-35	36-40	Older
-------	-------	-------	-------	-------	-------

#### 2. Did you have any health-related issues during the pregnancy?

*ie. high blood pressure, high cholesterol, severe infections etc.*

*Please tick appropriate box*

Yes	No	I don't know
-----	----	--------------

If yes, please describe what the health-related issue was.

.....

.....

#### 3. Did you consume alcohol during your pregnancy?

*Please tick appropriate box*

Yes	No
-----	----

If yes, please indicate how many drinks per day/week

.....

#### 4. Did you smoke during your pregnancy?

Please tick appropriate box

Yes	No
-----	----

If yes, please indicate how much and how often

.....

#### 5. Was the child born at full-term (38-40 weeks)?

Please tick appropriate box

Yes	No	I don't know
-----	----	--------------

If no, please indicate at what stage (in weeks) the child was born

.....

#### 6. Were there any health-related problems during the delivery for you or your child?

Please tick appropriate box

Yes	No	I don't know
-----	----	--------------

If yes, please describe what the health-related problem was

.....

.....

#### 7. Did your child achieve all the normal developmental milestones from birth to 18 months?

Please tick appropriate box

Yes	No	I don't know
-----	----	--------------

If no, please describe any differences you saw in your child's milestones

.....

.....

**8. From 18 months until now, have you noticed that your child has developed differently to other children?**

*Please tick appropriate box*

Yes	No	I don't know
-----	----	--------------

If yes, please describe what you have noticed with your child's development

.....

.....

**9. Is your child relatively the same size (height and build) as other children his/her age?**

*Please tick appropriate box*

Yes	No	I don't know
-----	----	--------------

If no, please describe how your child's size is different to other children

.....

.....

**10. Does your child have any chronic health-related problems?**

*ie. heart disease, lung disease, muscle or bone related problems, chronic pain*

*Please tick appropriate box*

Yes	No	I don't know
-----	----	--------------

If yes, please describe what chronic health-related problem your child has

.....

.....

**Thank you for your time and co-operation!**

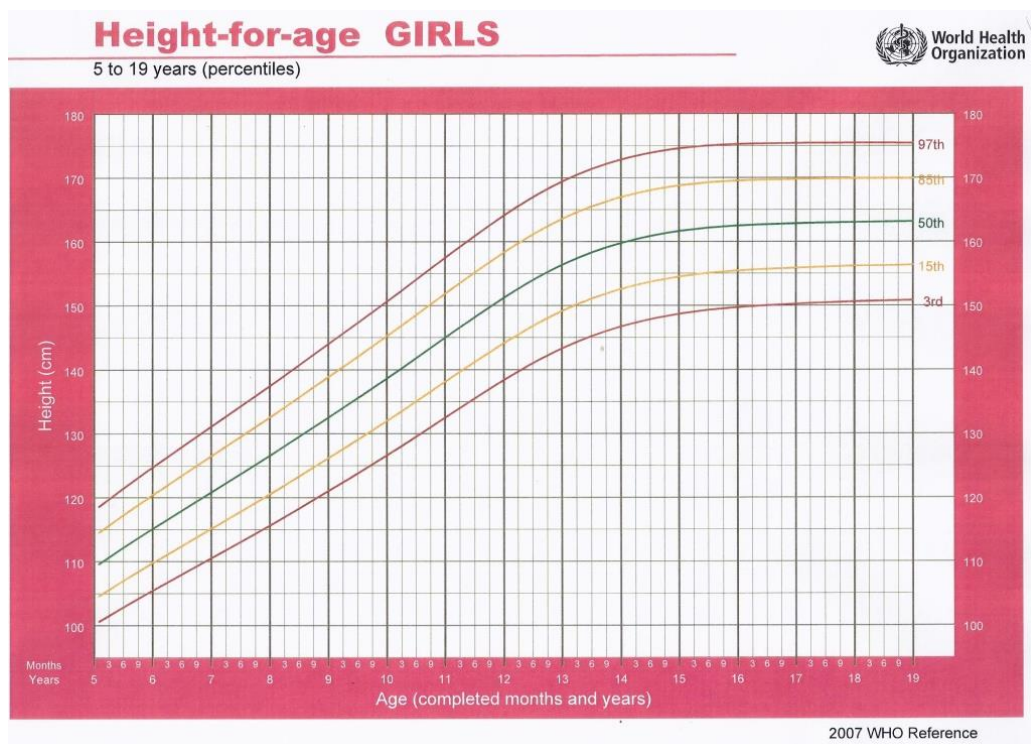
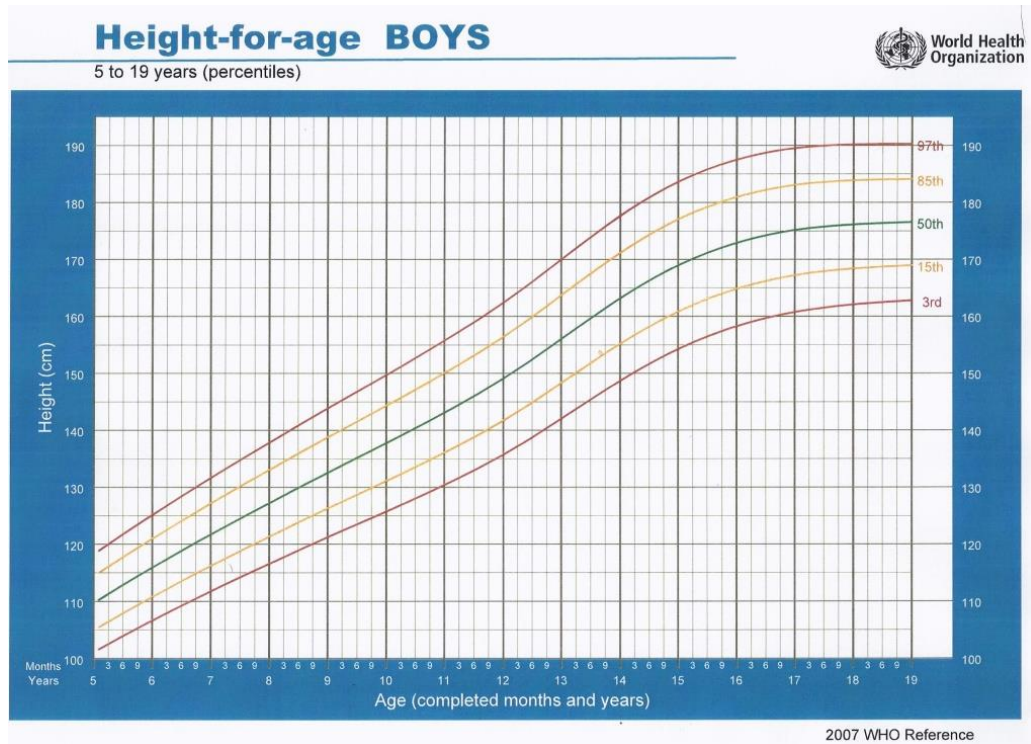
**If you have any questions or concerns please do not hesitate to contact the principal researcher, Keryn Moore, on 0741019859.**



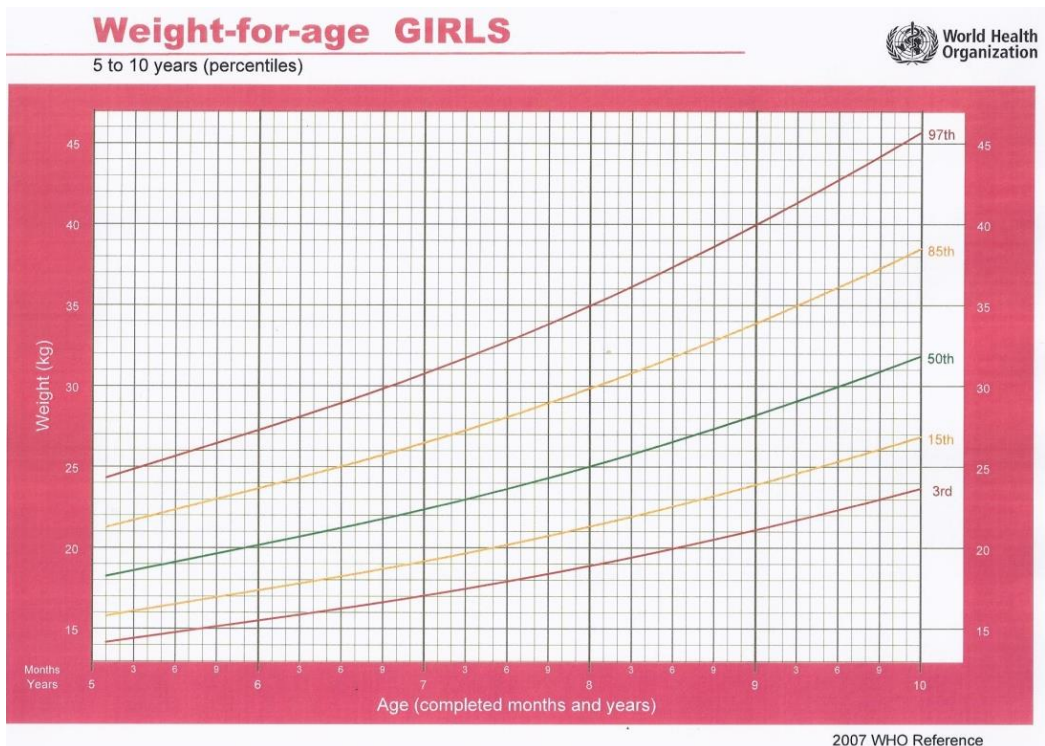
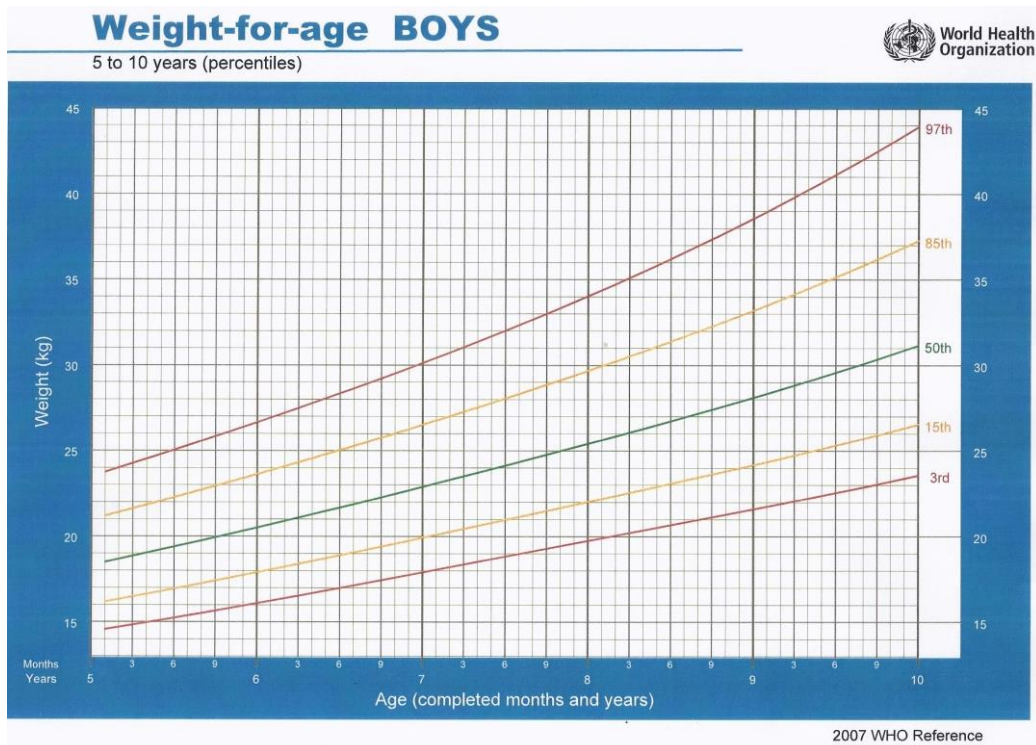
## Addendum I

### Percentile and reference charts

#### Height-for-age percentile charts



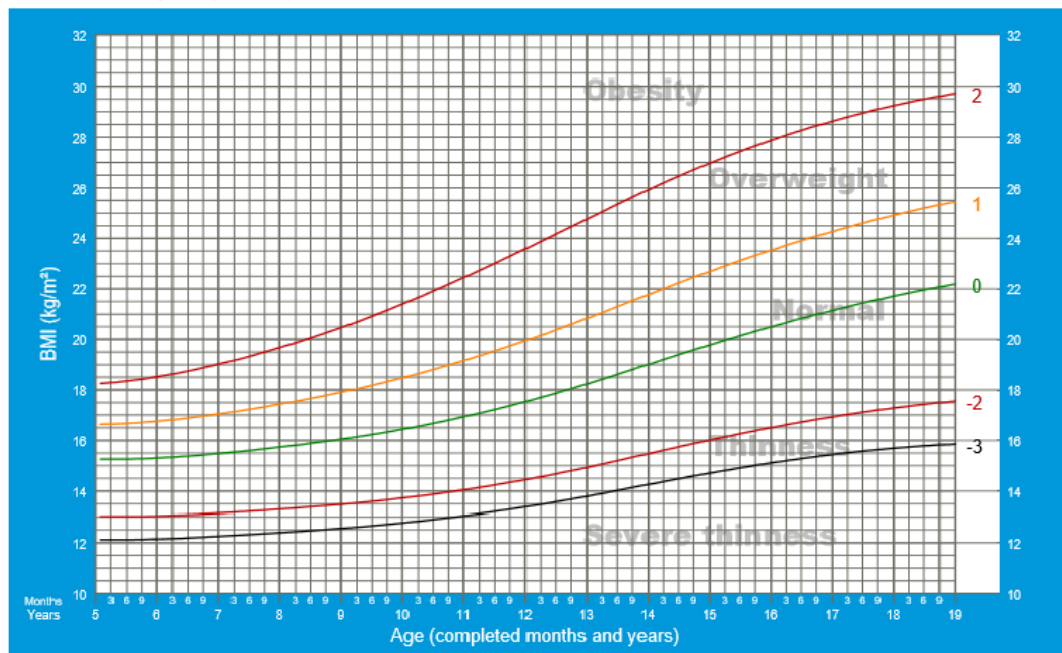
## Weight-for-age percentile charts



## BMI-for-age percentile charts

### BMI-for-age BOYS

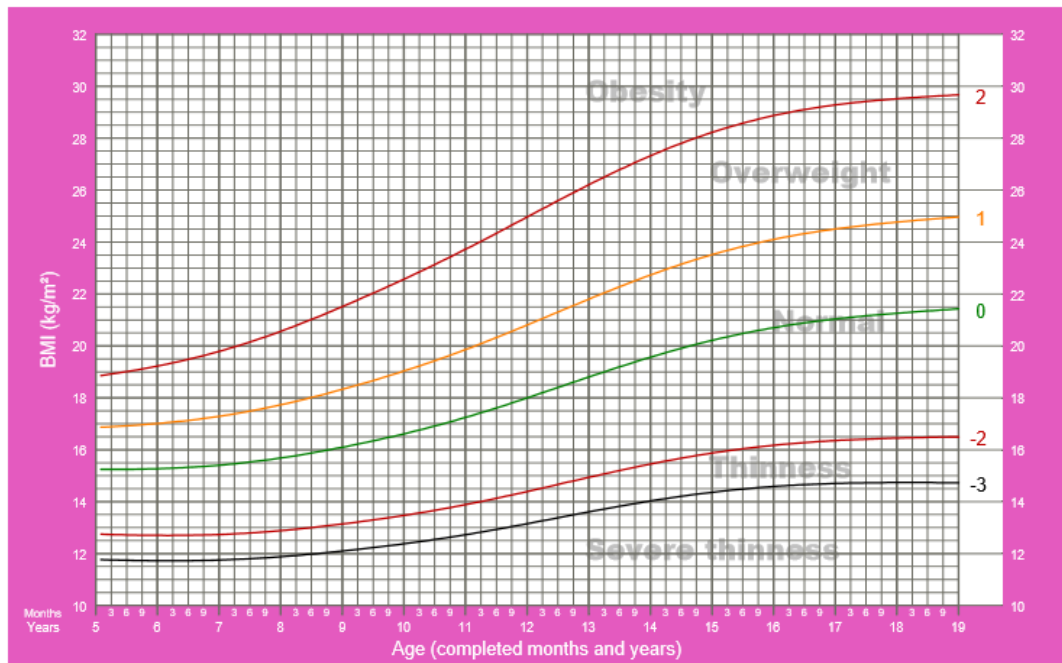
5 to 19 years (z-scores)



2007 WHO Reference

### BMI-for-age GIRLS

5 to 19 years (z-scores)

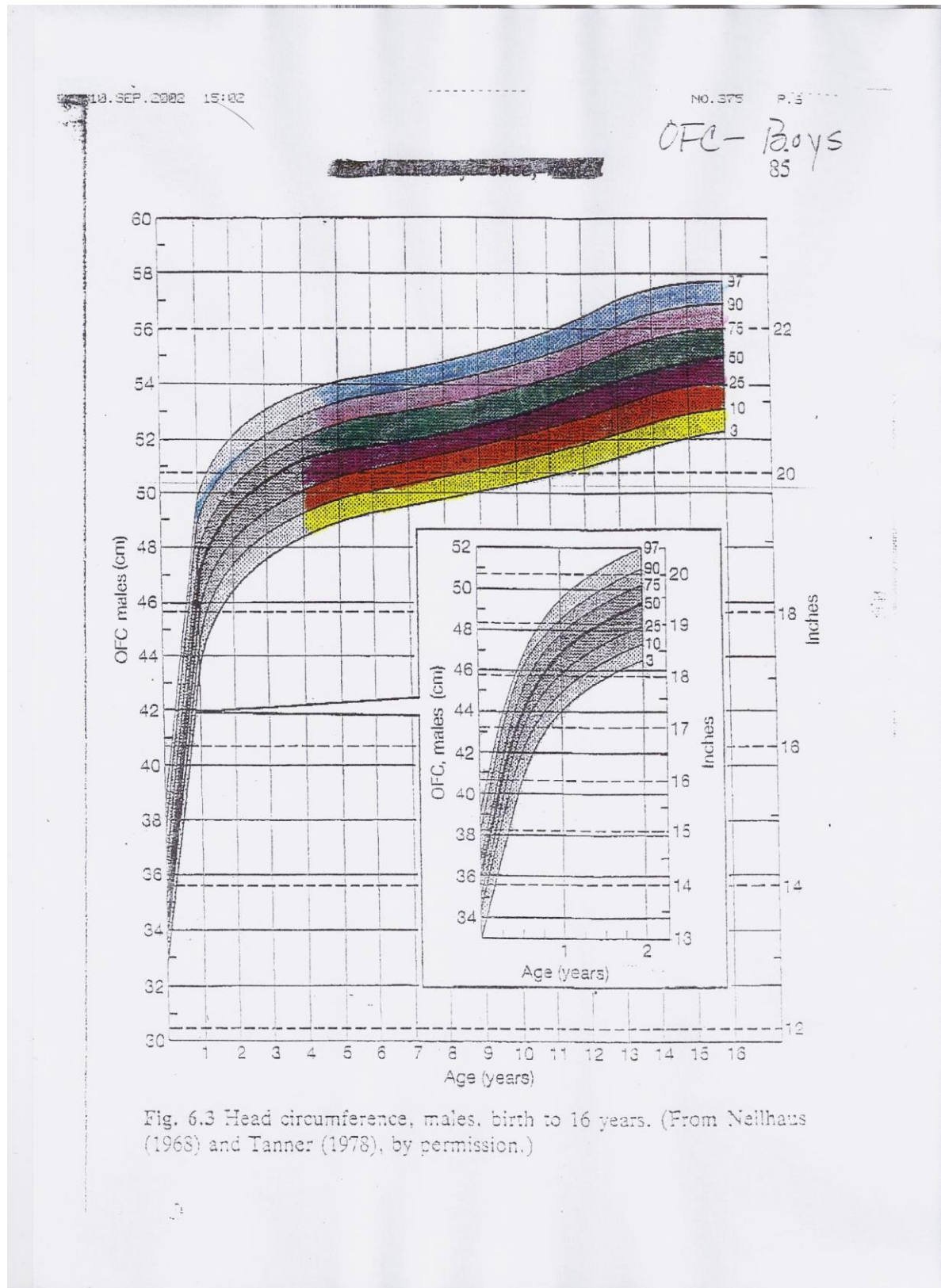


2007 WHO Reference



# Occipital frontal circumference reference chart for boys

(As used by the Fetal Alcohol Syndrome Epidemiology Research (FASER) group)



## Occipital frontal circumference reference chart for girls

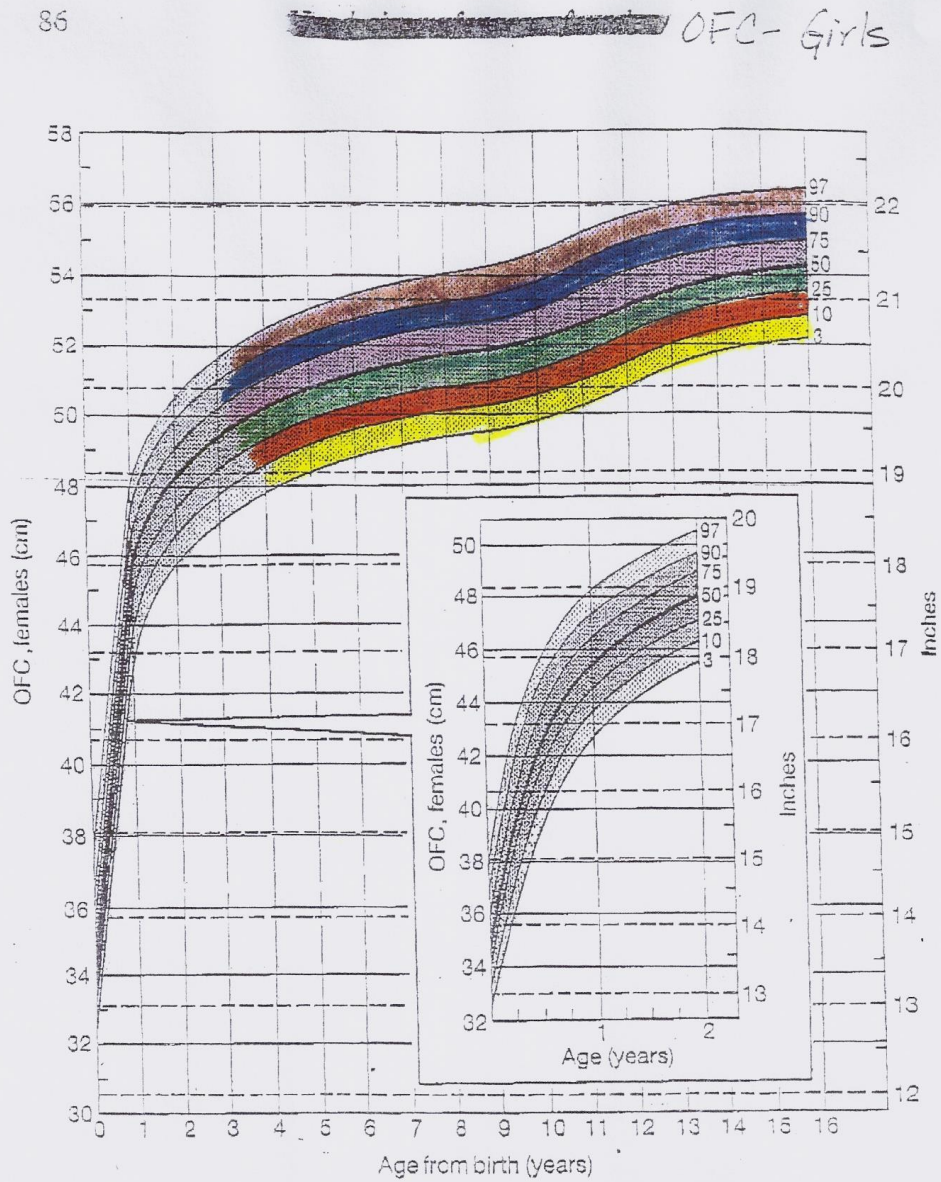


Fig. 6.4 Head circumference, females, birth to 16 years. (From Nellhaus (1968) and Tanner (1978), by permission.)

## Addendum J

### Ethical approval (urban study)



UNIVERSITEIT • STELLENBOSCH • UNIVERSITY  
jou kennisvenoot • your knowledge partner

#### Approval Notice Response to Deferral

02-Feb-2016  
Moore, Keryn K

**Ethics Reference #:** S15/09/207

**Title:** Single-leg hopping in children with and without Fetal Alcohol Spectrum Disorders: A descriptive study of postural stability and movement kinematics

Dear Miss Keryn Moore,

The **Response to Deferral - (New Application)** received on **03-Dec-2015**, was reviewed by members of **Health Research Ethics Committee 1** via Expedited review procedures on **02-Feb-2016** and was approved.  
Please note the following information about your approved research protocol:

Protocol Approval Period: **02-Feb-2016 -01-Feb-2017**

Please remember to use your **protocol number** (**S15/09/207**) on any documents or correspondence with the HREC concerning your research protocol.

Please note that the HREC has the prerogative and authority to ask further questions, seek additional information, require further modifications, or monitor the conduct of your research and the consent process.

#### After Ethical Review:

Please note a template of the progress report is obtainable on [www.sun.ac.za/rds](http://www.sun.ac.za/rds) and should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary). Annually a number of projects may be selected randomly for an external audit.  
Translation of the consent document to the language applicable to the study participants should be submitted.

Federal Wide Assurance Number: 00001372  
Institutional Review Board (IRB) Number: IRB0005239

The Health Research Ethics Committee complies with the SA National Health Act No.61 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 Part 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

#### **Provincial and City of Cape Town Approval**

Please note that for research at a primary or secondary healthcare facility permission must still be obtained from the relevant authorities (Western Cape Department of Health and/or City Health) to conduct the research as stated in the protocol. Contact persons are Ms Claudette Abrahams at Western Cape Department of Health ([healthres@pgwc.gov.za](mailto:healthres@pgwc.gov.za) Tel: +27 21 483 9907) and Dr Helene Visser at City Health ([Helene.Visser@capetown.gov.za](mailto:Helene.Visser@capetown.gov.za) Tel:

+27 21 400 3981). Research that will be conducted at any tertiary academic institution requires approval from the relevant hospital manager. Ethics approval is required BEFORE approval can be obtained from these health authorities.

We wish you the best as you conduct your research.

For standard HREC forms and documents please visit: [www.sun.ac.za/rds](http://www.sun.ac.za/rds)

If you have any questions or need further assistance, please contact the HREC office at 0219389657.

**Included Documents:**

Investigator Declaration - Q Louw  
20151214 MOD Protocol  
Investigator Declaration - K Moore  
Supervisor CV - Y Brink  
Health General Checklist  
Investigator CV - Q Louw  
Supervisor Declaration - Y Brink  
Investigator CV - J Cockcroft  
Protocol, Synopsis, ICF & Addendums  
Application Form  
Investigator Declarations - J Cockcroft  
Investigator CV - K Moore  
20151214 MOD Cover letter

Sincerely,

Franklin Weber  
HREC Coordinator  
Health Research Ethics Committee 1



# Investigator Responsibilities

## Protection of Human Research Participants

Some of the responsibilities investigators have when conducting research involving human participants are listed below:

1. Conducting the Research. You are responsible for making sure that the research is conducted according to the HREC approved research protocol. You are also responsible for the actions of all your co-investigators and research staff involved with this research.
2. Participant Enrolment. You may not recruit or enrol participants prior to the HREC approval date or after the expiration date of HREC approval. All recruitment materials for any form of media must be approved by the HREC prior to their use. If you need to recruit more participants than was noted in your HREC approval letter, you must submit an amendment requesting an increase in the number of participants.
3. Informed Consent. You are responsible for obtaining and documenting effective informed consent using **only** the HREC-approved consent documents, and for ensuring that no human participants are involved in research prior to obtaining their informed consent. Please give all participants copies of the signed informed consent documents. Keep the originals in your secured research files for at least fifteen (15) years.
4. Continuing Review. The HREC must review and approve all HREC-approved research protocols at intervals appropriate to the degree of risk but not less than once per year. There is **no grace period**. Prior to the date on which the HREC approval of the research expires, **it is your responsibility to submit the continuing review report in a timely fashion to ensure a lapse in HREC approval does not occur**. If HREC approval of your research lapses, you must stop new participant enrolment, and contact the HREC office immediately.
5. Amendments and Changes. If you wish to amend or change any aspect of your research (such as research design, interventions or procedures, number of participants, participant population, informed consent document, instruments, surveys or recruiting material), you must submit the amendment to the HREC for review using the current Amendment Form. You **may not initiate** any amendments or changes to your research without first obtaining written HREC review and approval. The **only exception** is when it is necessary to eliminate apparent immediate hazards to participants and the HREC should be immediately informed of this necessity.
6. Adverse or Unanticipated Events. Any serious adverse events, participant complaints, and all unanticipated problems that involve risks to participants or others, as well as any research-related injuries, occurring at this institution or at other performance sites must be reported to the HREC within **five (5) days** of discovery of the incident. You must also report any instances of serious or continuing problems, or non-compliance with the HREC's requirements for protecting human research participants. The only exception to this policy is that the death of a research participant must be reported in accordance with the Stellenbosch University Health Research Ethics Committee Standard Operating Procedures [www.sun025.sun.ac.za/portal/page/portal/Health\\_Sciences/English/Centres%20and%20Institutions/Research\\_Development\\_Support/Ethics/Application\\_package](http://www.sun025.sun.ac.za/portal/page/portal/Health_Sciences/English/Centres%20and%20Institutions/Research_Development_Support/Ethics/Application_package). All reportable events should be submitted to the HREC using the Serious Adverse Event Report Form.
7. Research Record Keeping. You must keep the following research-related records, at a minimum, in a secure location for a minimum of fifteen years: the HREC approved research protocol and all amendments; all informed consent documents; recruiting materials; continuing review reports; adverse or unanticipated events; and all correspondence from the HREC.
8. Reports to the MCC and Sponsor. When you submit the required annual report to the MCC or you submit required reports to your sponsor, you must provide a copy of that report to the HREC. You may submit the report at the time of continuing HREC review.
9. Provision of Emergency Medical Care. When a physician provides emergency medical care to a participant without prior HREC review and approval, to the extent permitted by law, such activities will not be recognised as research nor will the data obtained by any such activities should it be used in support of research.
10. Final reports. When you have completed (no further participant enrolment, interactions, interventions or data analysis) or stopped work on your research, you must submit a Final Report to the HREC.
11. On-Site Evaluations, MCC Inspections, or Audits. If you are notified that your research will be reviewed or audited by the MCC, the sponsor, any other external agency or any internal group, you must inform the HREC immediately of the impending audit/evaluation.



**Addendum K****Health questionnaire results (total sample group)**

<b>Question 1</b>	<b>15-20years</b>	<b>21-25years</b>	<b>26-30years</b>	<b>30-35years</b>	<b>36-40years</b>	<b>Other</b>
	n=9	n=9	n=10	n=8	n=6	n=0
	<b>Yes</b>		<b>No</b>		<b>I don't know</b>	
	<b>Male</b>	<b>Female</b>	<b>Male</b>	<b>Female</b>	<b>Male</b>	<b>Female</b>
<b>Question 2</b>	4	4	17	15	2	0
<b>Question 3</b>	3	1	20	18	0	0
<b>Question 4</b>	7	2	15	17	1	0
<b>Question 5</b>	19	17	3	2	1	0
<b>Question 6</b>	5	2	16	17	2	0
<b>Question 7</b>	21	14	1	5	1	0
<b>Question 8</b>	2	3	19	15	2	1
<b>Question 9</b>	20	18	2	1	1	0
<b>Question 10</b>	1	0	22	19	0	0

Please refer to the health questionnaire in Addendum H.

## Addendum L

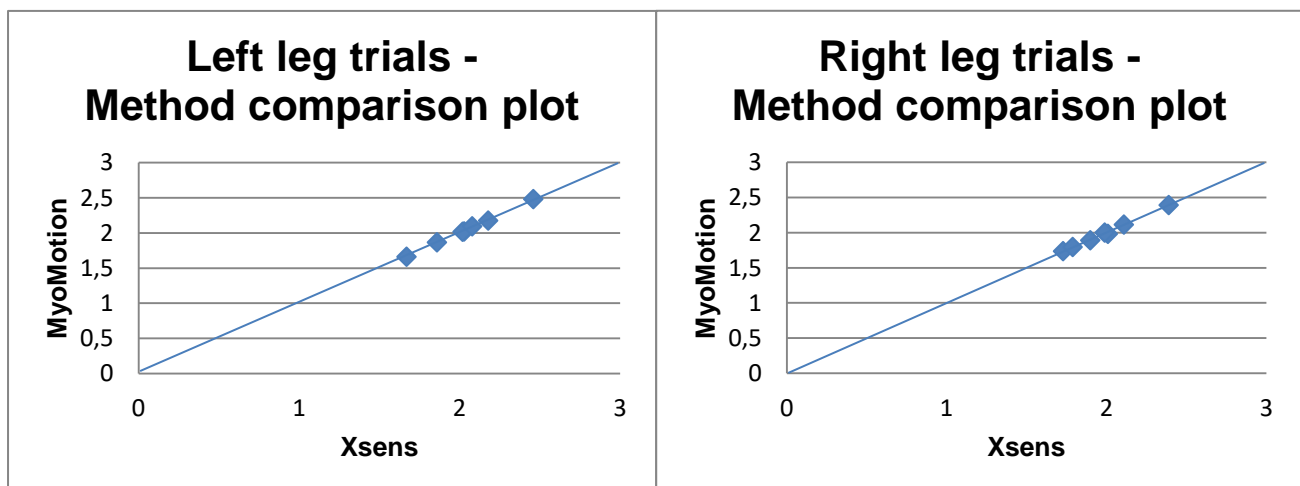
### Concurrent validity testing for spatiotemporal parameters

To determine the agreement between the Xsens and MyoMotion systems measurements, the spatiotemporal data of the seven children tested with both systems were plotted on method comparison and Bland-Altman plots, seen below.

#### Total trial time

Total trial time was one of the spatiotemporal outcome measures used to determine the parameter of speed of the trial. The distance of the hopping area was divided by the total trial time.

#### Method comparison plots



1a.) 1b.)  
**Figures 1a.) and 1b) Method comparison plots indicating amount of agreement between the two measurement methods for total trial time (s) (foot contact 1 to foot contact 5) of left and right leg trials**

The method comparison plots indicate that the two measurement systems are in close agreement for the measurement of total trial time for both left and right leg trials, as all scores fall directly on the line of identity (emerging from the origin) (Portney & Watkins, 2009).

## Bland-Altman plots

In order to further examine the agreement between systems the spread of the difference scores was plotted on Bland-Altman plots (Figure 1c.; 1d.) (Bland, 1990). The dashed line indicates the mean difference score and the upper and lower limit agreement lines represent 2 SD above and below the mean difference.

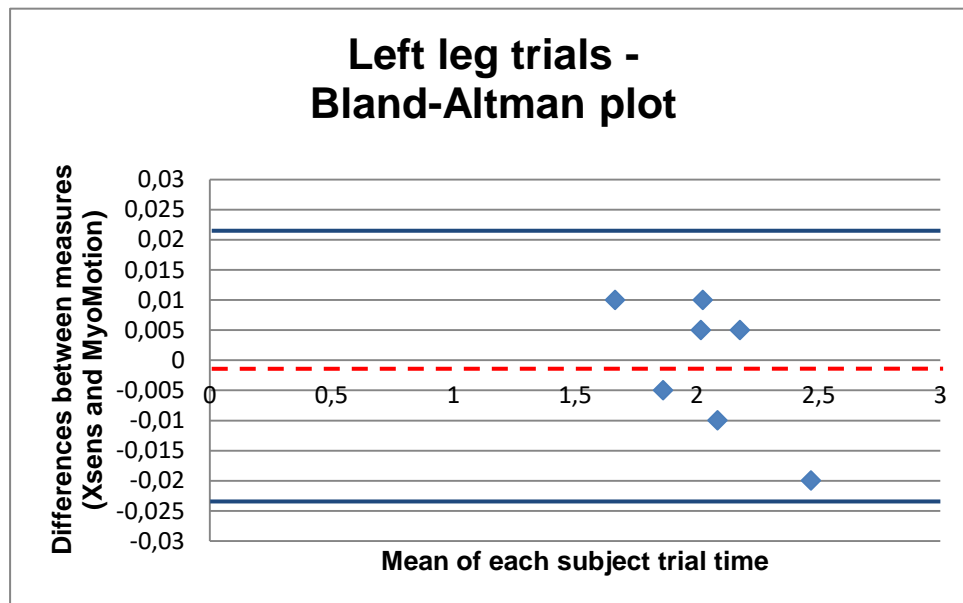


Figure 1c.) Bland-Altman plot displaying differences between Xsens and MyoMotion measures plotted against the mean of the trial time for each subject for left leg trials

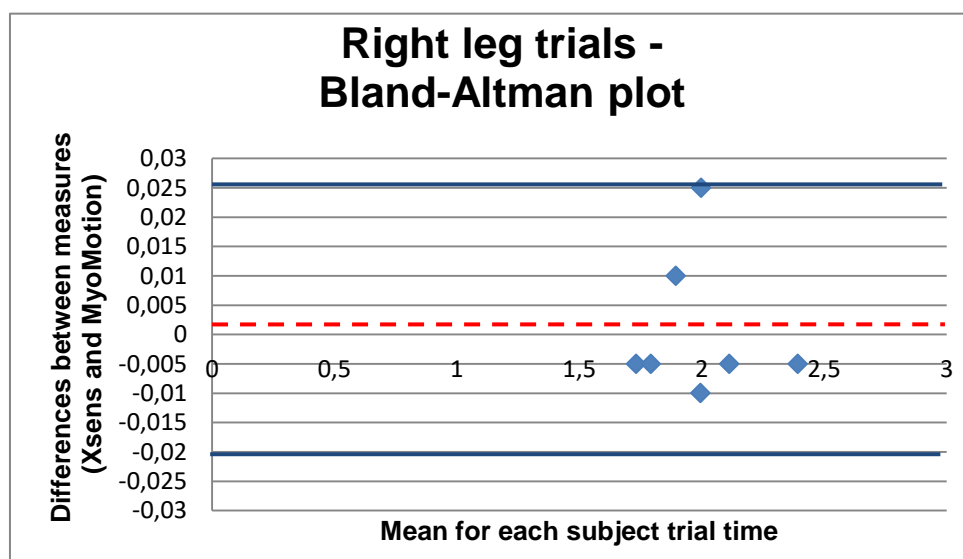
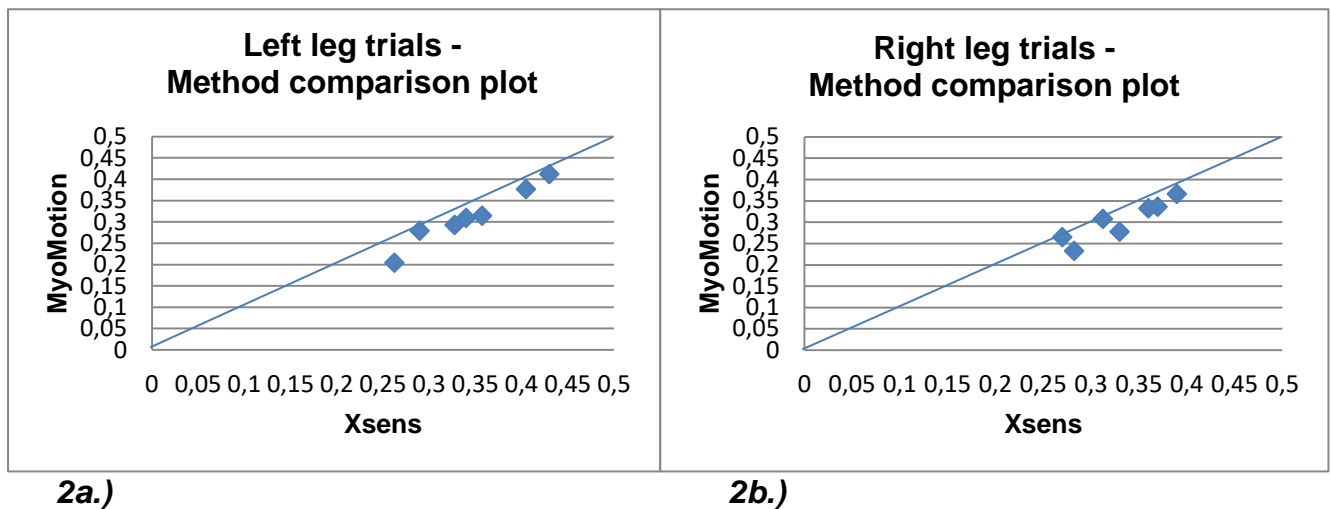


Figure 1d.) Bland-Altman plot displaying differences between Xsens and MyoMotion measures plotted against the mean of the trial time for each subject for right leg trials

All scores for the total trial time fall within the 95% limits of agreement range on the Bland-Altman plots, indicating close agreement between the two systems for both left and right leg trials.

## **Stance time**

### **Method comparison plots**



**Figures 2a.) and 2b.) Method comparison plots indicating amount of agreement between the two measurement methods for stance time (s) of left and right leg trials**

These plots indicate less agreement between measurement systems for stance time. One score for the left leg trials and two scores for the right leg trials fall directly on the line of identity, indicating slightly more variability between the systems. The Xsens consistently produced larger values for stance time compared to the MyoMotion system. To determine whether the difference of scores fell within the upper and lower 95% limits of agreement, Bland-Altman plots were examined (Figures 2c.; 2d.).

## Bland-Altman plots

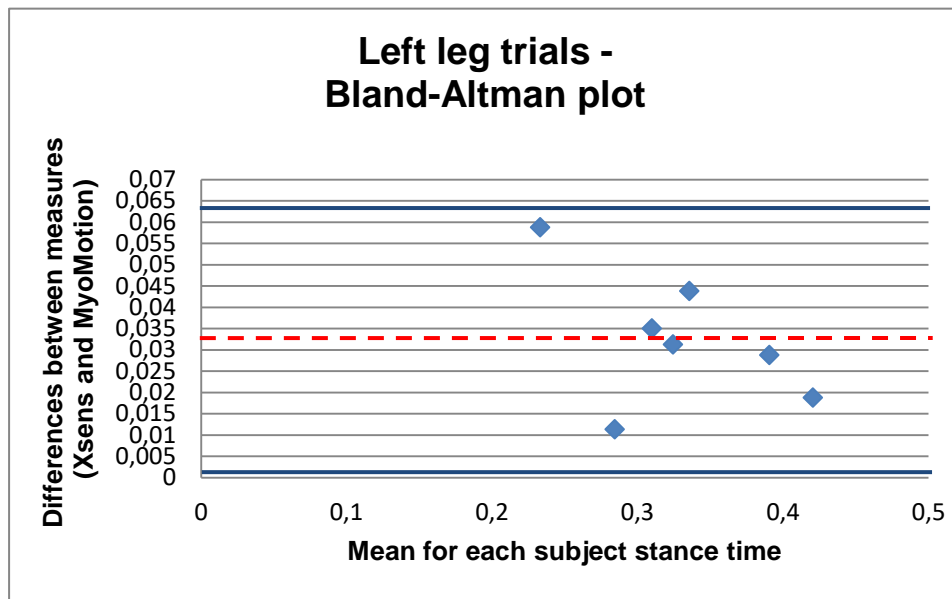


Figure 2c.) Bland-Altman plot displaying differences between Xsens and MyoMotion measures plotted against the mean of stance time for each subject for left leg trials

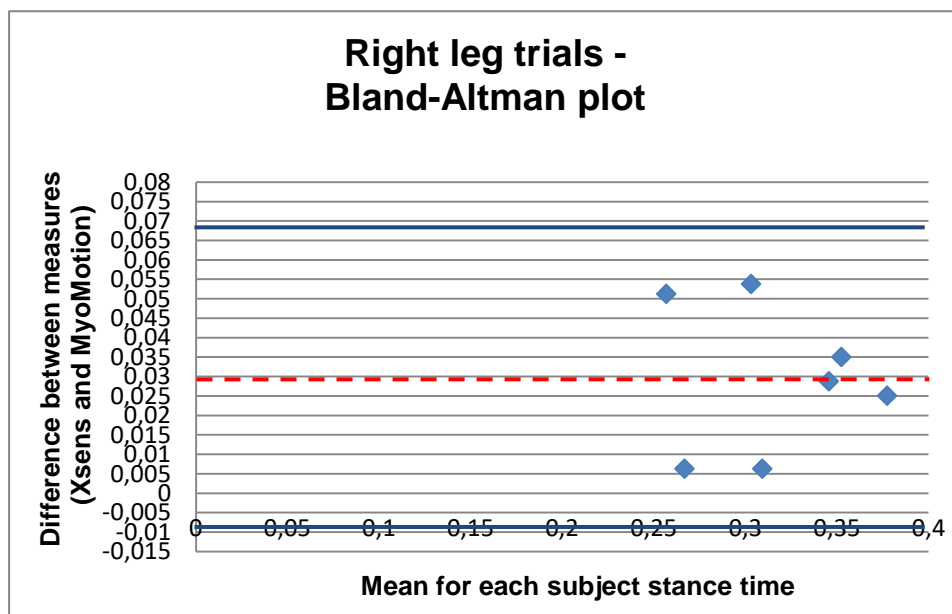


Figure 2d.) Bland-Altman plot displaying differences between Xsens and MyoMotion measures plotted against mean of the stance time for each subject for right leg trials

All stance time scores fall within the 95% limits of agreement range on the Bland-Altman plots, indicating fair agreement between the two systems for both left and right leg trials.



## Bland-Altman plots

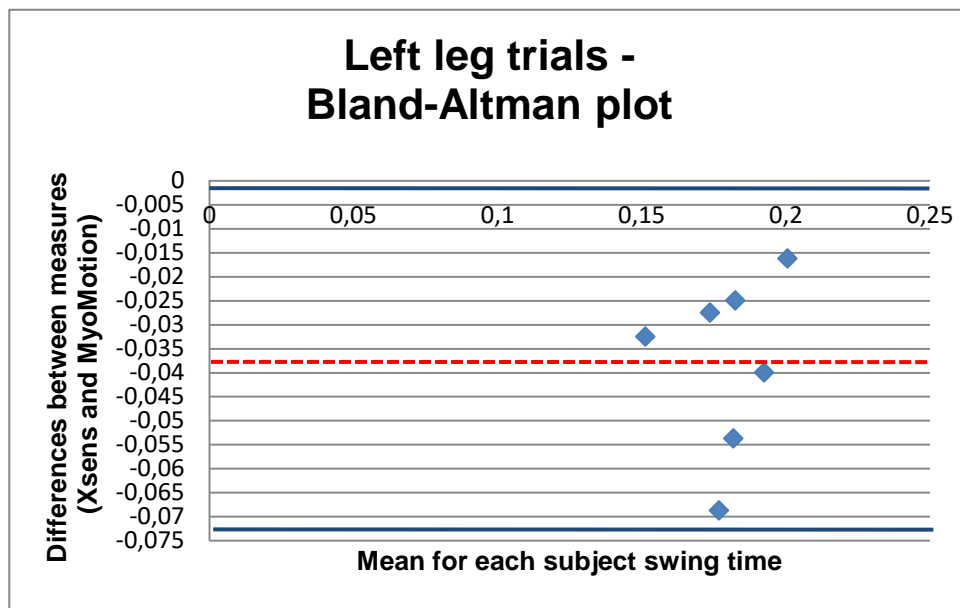


Figure 3c.) Bland-Altman plot displaying differences between Xsens and MyoMotion measures plotted against mean of the swing time for each subject for left leg trials

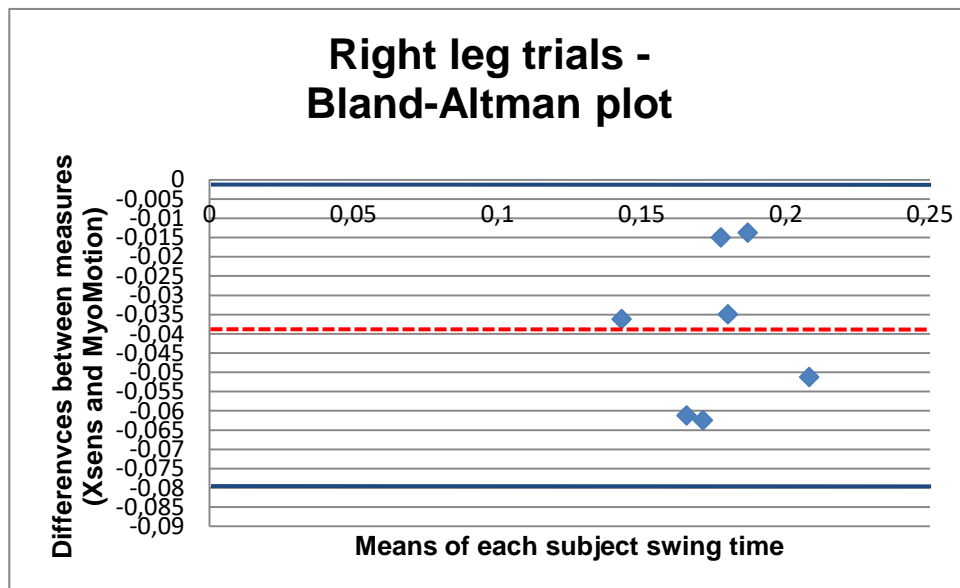


Figure 3d.) Bland-Altman plot displaying differences between Xsens and MyoMotion measures plotted against mean of the swing time for each subject for right leg trials

All swing time scores fall within the 95% limits of agreement range on the Bland-Altman plots for both left and right leg trials. This indicates that despite the greater variability of measures shown on the method-comparison plot, the measurement scores are in fair agreement between systems.

**Addendum M****Descriptive results tables displaying mean (SD) values for all parameters****Table M1. The mean (SD) of spatiotemporal parameters during the movement phase of single leg hopping**

<b>Temporal</b>	<b>Rural cases</b>			<b>Rural controls</b>			<b>Urban controls</b>		
	<b>Group n = 21</b>	<b>Male n = 13</b>	<b>Female n = 8</b>	<b>Group n = 26</b>	<b>Male n = 15</b>	<b>Female n = 11</b>	<b>Group n = 53</b>	<b>Male n = 23</b>	<b>Female n = 30</b>
<b>Stance time (s)</b>	0.37 (0.13)	0.41 (0.15)	0.30 (0.03)	0.38 (0.11)	0.41 (0.13)	0.33 (0.05)	0.87 (0.23)	0.88 (0.23)	0.87 (0.23)
<b>Swing time (s)</b>	0.16 (0.02)	0.16 (0.02)	0.16 (0.02)	0.15 (0.03)	0.15 (0.02)	0.15 (0.05)	0.22 (0.08)	0.22 (0.09)	0.22 (0.08)
<b>Speed of trial (m.s<sup>-1</sup>)</b>	0.90 (0.18)	0.84 (0.20)	0.99 (0.09)	0.88 (0.15)	0.83 (0.17)	0.94 (0.08)	0.87 (0.14)	0.86 (0.12)	0.88 (0.16)

n: number of trials; s: seconds; m: metres



**Table M2. The mean (SD) of COP parameters during the landing phase of single leg hopping**

<b>COP</b>	<b>Rural Cases</b>			<b>Rural controls</b>			<b>Urban controls</b>		
	<b>Group n = 15</b>	<b>Male n = 8</b>	<b>Female n = 7</b>	<b>Group n = 20</b>	<b>Male n = 12</b>	<b>Female n = 8</b>	<b>Group n = 48</b>	<b>Male n = 22</b>	<b>Female n = 26</b>
<b>AP<sub>vel</sub> (cm.<sup>-1</sup>)</b>	37.09 (12.44)	33.15 (12.31)	41.60 (11.83)	35.96 (10.95)	32.79 (8.10)	40.71 (13.39)	19.85 (23.19)	21.74 (29.28)	18.11 (16.09)
<b>ML<sub>vel</sub> (cm.<sup>-1</sup>)</b>	10.68 (2.18)	11.20 (2.19)	10.09 (2.18)	12.55 (4.16)	12.20 (4.44)	13.09 (3.93)	44.89 (23.65)	46.59 (26.15)	43.32 (21.49)
<b>AP ROM (cm)</b>	10.37 (3.78)	9.33 (4.24)	11.56 (3.04)	10.09 (3.21)	10.79 (3.17)	9.03 (3.18)	5.43 (8.42)	5.39 (9.20)	5.47 (7.82)
<b>ML ROM (cm)</b>	2.55 (0.97)	2.55 (0.99)	2.55 (1.03)	3.19 (1.30)	3.39 (1.49)	2.88 (0.96)	12.06 (7.09)	11.77 (6.99)	12.32 (7.31)
<b>TTS (s)</b>	0.57 (0.16)	0.56 (0.16)	0.58 (0.17)	0.69 (0.25)	0.75 (0.29)	0.60 (0.16)	0.66 (0.22)	0.68 (0.26)	0.65 (0.18)

n: number of trials; COP: centre of pressure; AP: anteroposterior, ML: mediolateral; vel: velocity; ROM: range of motion; cm: centimetres; s: seconds

**Table M3. The mean (SD) of maximum and minimum values and ROM for sagittal plane kinematics of the hip joint**

	Cases			Rural controls			Urban controls		
	Group n = 11	Males n = 6	Females n = 5	Group n = 19	Males n = 12	Females n = 7	Group n = 51	Males n = 22	Females n = 29
<b>Maximum° Hop 1</b>	29.71 (6.22)	29.07 (5.54)	30.48 (7.55)	28.70 (8.89)	31.45 (9.91)	23.99 (4.02)	34.88 (10.26)	37.96 (10.36)	32.55 (9.72)
<b>Hop 2</b>	26.46 (5.14)	25.91 (6.02)	27.13 (4.44)	28.54 (8.11)	30.84 (9.00)	24.58 (4.46)	32.62 (9.29)	34.03 (10.36)	31.55 (8.43)
<b>Hop 3</b>	28.48 (6.34)	29.38 (6.48)	27.41 (6.74)	28.66 (8.48)	30.79 (9.77)	25.00 (4.02)	30.82 (8.71)	32.83 (10.24)	29.29 (7.15)
<b>Hop 4</b>	29.35 (7.01)	30.89 (5.58)	27.50 (8.73)	28.97 (8.11)	31.83 (8.43)	24.09 (4.80)	30.54 (8.22)	33.25 (8.51)	28.48 (7.50)
<b>Mean (SD) of four hops°</b>	28.50 (1.45)	28.81 (2.09)	28.13 (1.57)	28.72 (0.19)	31.23 (0.50)	24.41 (0.47)	32.21 (2.00)	34.52 (2.35)	30.47 (1.90)
<b>Minimum° Hop 1</b>	-2.13 (6.28)	-3.05 (5.20)	-1.02 (7.87)	2.97 (8.10)	5.96 (8.24)	-2.16 (4.86)	6.85 (9.42)	10.39 (9.02)	4.16 (8.94)
<b>Hop 2</b>	-2.61 (6.08)	-2.09 (6.90)	-3.23 (5.67)	0.93 (7.41)	4.38 (6.83)	-4.99 (3.81)	4.95 (8.21)	7.12 (9.23)	3.31 (7.08)
<b>Hop 3</b>	-1.17 (8.20)	1.28 (9.03)	-4.11 (6.83)	1.06 (8.14)	4.35 (8.13)	-4.59 (4.34)	4.67 (8.44)	7.87 (9.48)	2.23 (6.74)
<b>Hop 4</b>	-0.33 (9.48)	0.54 (8.71)	-1.38 (11.28)	1.82 (8.22)	5.11 (8.28)	-3.81 (4.26)	5.31 (8.79)	8.86 (9.65)	2.63 (7.12)
<b>Mean (SD) of four hops°</b>	-1.56 (1.02)	-0.83 (2.07)	-2.43 (1.48)	1.69 (0.94)	4.95 (0.76)	-3.89 (1.25)	5.44 (0.97)	8.56 (1.41)	3.08 (0.85)
<b>ROM° (max - min)</b>	30.06	29.64	30.56	27.03	26.28	28.3	26.77	25.96	27.39

n: number of trials; SD: standard deviation; max: maximum; min: minimum

**Table M4. The mean (SD) of maximum and minimum values and ROM for sagittal plane kinematics of the knee joint**

	Cases			Rural controls			Urban controls		
	Group n = 11	Males n = 6	Females n = 5	Group n =19	Males n = 12	Females n = 7	Group n = 51	Males n = 22	Females n = 29
Maximum° Hop 1	47.13 (14.38)	50.01 (17.94)	43.68 (9.32)	51.57 (8.48)	49.42 (8.85)	55.26 (6.84)	54.12 (11.78)	56.35 (12.60)	52.43 (11.04)
	47.51 (16.83)	50.38 (21.91)	44.08 (8.99)	52.81 (9.35)	49.53 (8.54)	58.43 (8.39)	54.04 (12.08)	55.94 (13.39)	52.60 (11.00)
	46.25 (15.01)	50.03 (19.35)	41.70 (6.92)	54.45 (8.23)	52.38 (8.02)	58.00 (7.88)	53.71 (12.06)	55.71 (13.91)	52.20 (10.45)
	46.92 (14.52)	51.56 (17.46)	41.35 (8.67)	53.25 (8.22)	51.45 (8.74)	56.33 (6.72)	53.86 (11.84)	56.11 (13.33)	52.15 (10.49)
Mean (SD) of four hops°	46.95 (0.53)	50.50 (0.73)	42.70 (1.37)	53.02 (1.19)	50.69 (1.46)	57.01 (1.47)	53.93 (0.18)	56.03 (0.27)	52.35 (0.21)
Minimum° Hop 1	12.90 (9.98)	15.07 (11.68)	10.30 (7.93)	16.70 (7.92)	12.74 (6.55)	23.49 (4.96)	16.88 (9.09)	17.99 (10.22)	16.04 (8.21)
	11.72 (9.46)	15.20 (11.32)	7.55 (4.86)	16.21 (6.19)	13.71 (5.72)	20.49 (4.61)	16.09 (8.30)	16.49 (8.77)	15.79 (8.07)
	12.56 (11.48)	16.37 (13.49)	7.99 (7.37)	14.42 (7.13)	11.99 (7.02)	18.58 (5.48)	16.40 (8.59)	16.56 (9.83)	16.28 (7.71)
	8.82 (9.31)	13.01 (9.96)	3.79 (5.89)	12.75 (6.90)	10.41 (6.97)	16.76 (4.89)	16.02 (8.29)	16.58 (9.83)	15.59 (7.07)
Mean (SD) of four hops°	11.50 (1.86)	14.91 (1.40)	7.41 (2.70)	15.02 (1.80)	12.21 (1.39)	19.83 (2.88)	16.35 (0.39)	16.91 (0.72)	15.93 (0.30)
ROM° (max - min)	35.45	35.59	35.29	38	38.48	37.18	37.58	39.12	36.42

n: number of trials; SD: standard deviation; max: maximum; min: minimum

**Table M5. The mean (SD) of maximum and minimum values and ROM for sagittal plane kinematics of the ankle joint**

		Cases			Rural controls			Urban controls		
		Group n = 11	Males n = 6	Females n = 5	Group n =19	Males n = 12	Females n = 7	Group n = 51	Males n = 22	Females n = 29
Maximum°	Hop 1	27.12 (9.38)	32.50 (9.42)	20.67 (3.68)	23.91 (10.98)	22.93 (13.26)	25.57 (5.83)	24.21 (6.81)	23.67 (7.09)	24.62 (6.69)
	Hop 2	27.80 (10.13)	33.16 (10.81)	21.37 (3.94)	25.20 (11.00)	24.55 (13.47)	26.32 (5.30)	24.05 (6.51)	24.41 (6.93)	23.78 (6.28)
	Hop 3	27.19 (9.21)	32.50 (9.62)	20.81 (1.84)	25.00 (13.56)	24.42 (17.06)	25.99 (4.00)	24.41 (7.05)	24.78 (7.77)	24.13 (6.58)
	Hop 4	26.26 (9.57)	31.46 (9.63)	20.01 (4.87)	24.64 (9.83)	23.09 (11.67)	27.29 (5.19)	24.74 (5.39)	24.96 (6.23)	24.58 (4.76)
Mean (SD) of four hops°		27.09 (0.63)	32.40 (0.70)	20.71 (0.56)	24.69 (0.57)	23.75 (0.85)	26.29 (0.73)	24.35 (0.30)	24.46 (0.49)	24.28 (0.40)
Minimum°	Hop 1	-4.06 (11.98)	-4.55 (10.45)	-8.55 (8.32)	-10.83 (10.00)	-12.30 (10.84)	-8.30 (8.53)	-14.10 (10.92)	-15.46 (11.30)	-13.07 (10.71)
	Hop 2	-4.68 (11.53)	-5.74 (12.10)	-7.96 (7.29)	-10.75 (10.29)	-11.34 (11.38)	-9.75 (8.86)	-14.02 (11.03)	-14.10 (9.50)	-13.97 (12.23)
	Hop 3	-5.16 (11.22)	-6.63 (11.61)	-7.94 (7.37)	-11.81 (10.26)	-13.03 (11.00)	-9.71 (9.26)	-15.10 (12.28)	-15.15 (11.88)	-15.07 (12.78)
	Hop 4	-6.80 (9.71)	-7.59 (10.43)	-9.08 (7.77)	-13.53 (10.45)	-14.83 (11.32)	-11.30 (9.12)	-14.38 (11.22)	-14.24 (9.75)	-14.48 (12.40)
Mean (SD) of four hops°		-5.17 (1.17)	-6.13 (1.29)	-8.38 (0.54)	-11.73 (1.29)	-12.87 (1.48)	-9.76 (1.23)	-14.40 (0.49)	-14.74 (0.67)	-14.14 (0.85)
ROM° (max - min)		32.26	38.53	29.09	36.42	36.62	36.68	38.75	39.2	38.42

n: number of trials; SD: standard deviation; max: maximum; min: minimum

**Table M6. The mean (SD) values of the hip, knee and ankle landing kinematics during the last land onto the pressure mat**

	<b>Cases</b>			<b>Rural controls</b>			<b>Urban controls</b>		
	<b>Group</b>	<b>Males</b>	<b>Females</b>	<b>Group</b>	<b>Males</b>	<b>Females</b>	<b>Group</b>	<b>Males</b>	<b>Females</b>
	<b>n = 11</b>	<b>n = 7</b>	<b>n = 4</b>	<b>n = 18</b>	<b>n = 11</b>	<b>n = 7</b>	<b>n = 51</b>	<b>n = 22</b>	<b>n = 29</b>
<b>Hip IFC °</b>	19.57 (6.49)	17.89 (5.02)	22.52 (8.48)	19.78 (10.90)	22.07 (12.68)	16.18 (6.64)	22.45 (8.31)	25.02 (9.2)	20.50 (7.11)
<b>Hip Maximum°</b>	23.49 (7.85)	22.74 (5.93)	24.79 (11.46)	23.83 (10.20)	25.38 (12)	21.39 (6.61)	30.54 (9.10)	34.34 (9.52)	27.67 (7.75)
<b>Knee IFC °</b>	27.34 (12.06)	28.09 (14.55)	26.03 (7.56)	30.10 (7.26)	27.90 (5.57)	33.55 (8.64)	19.41 (10.18)	21.55 (11.94)	17.27 (9.04)
<b>Knee Maximum°</b>	39.03 (12.01)	42.30 (14.17)	33.33 (3.31)	46.81 (9.79)	44.64 (11.29)	50.20 (6.09)	46.30 (12.40)	48.24 (13.72)	45.00 (10.54)
<b>Ankle IFC °</b>	4.86 (7.67)	8.14 (2.95)	-0.86 (10.49)	1.30 (8.78)	-0.73 (10.12)	4.48 (5.34)	-6.16 (10.06)	-3.17 (8.34)	-8.43 (10.78)
<b>Ankle Maximum°</b>	13.91 (4.96)	16.39 (4.06)	9.57 (3.11)	13.79 (8.31)	12.49 (9.85)	15.84 (5.08)	12.55 (6.08)	12.39 (7)	12.66 (5.40)

n: number of trials; IFC: initial foot contact